On behalf of the Respondents, I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to evaluate the information submitted. I certify that the information contained in or accompanying this report, Carbon Dioxide Injection Pilot Study Results, is true, accurate, and complete. As to those portions of the report for which I cannot personally verify accuracy, I certify under penalty of law that this report and all attachments were prepared in accordance with procedures designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who may manage the system or those directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

By: Kathleen Goodman    Date: May 15, 2020

Kathleen Goodman, Project Coordinator

# Carbon Dioxide Neutralization Pilot Study Results

Former Rhone-Poulenc Site
Tukwila, Washington

Wood Project #0087690050.000010

Prepared for:

**Container Properties, LLC**
Tukwila, Washington

May 15, 2020

# Carbon Dioxide Neutralization Pilot Study Results

Former Rhone-Poulenc Site
Tukwila, Washington
Container Properties, LLC

**Prepared for:**

Container Properties, LLC
Tukwila, Washington

**Prepared by:**

Wood Environment & Infrastructure Solutions, Inc.
600 University Street, Suite 600
Seattle, Washington 98101
USA
T: 206-342-1760

Wood Project #0087690050.000010

**May 15, 2020**

## Third-party disclaimer

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## Appendices

## List of acronyms and abbreviations

| | |
|---|---|
| µg/L | microgram per liter |
| °C | degrees Celsius |
| bgs | below ground surface |
| CMS | Corrective Measures Study |
| $CaCO_3$ | calcium carbonate |
| $CO_2$ | carbon dioxide |
| COC | constituent of concern |
| D | deep (for well identifier) |
| DQO | data quality objective |
| EPA | U.S. Environmental Protection Agency |
| EPCRA | Emergency Planning and Community Right-to-Know Act |
| HCIM | hydraulic control interim measure |
| HCIM Area | portion of the site enclosed within a low-permeability subsurface barrier wall |
| HDPE | high density polyethylene |
| high pH target area | area within the Shoreline Area inside the pH 8.5 contour |
| HV | hand valve |
| IMW | injection monitoring well |
| LAZ | lower aquifer zone |
| mg/L | milligram per liter |
| mL | milliliter |
| ML-SM | silt and silty sand |
| Order | Administrative Order on Consent No. 1091-11-20-3008(h) |
| pilot study | $CO_2$ neutralization pilot study |
| PR | pressure regulator |
| PRG | preliminary remediation goals |
| PSCAA | Puget Sound Clean Air Agency |
| psi | pounds per square inch |
| psig | gauge pounds per square inch |
| PVC | polyvinyl chloride |
| QAPP | Quality Assurance Project Plan |
| Report | Carbon Dioxide Neutralization Pilot Study Report |
| ROI | radius of influence |
| S | shallow (for well identifier) |
| SCFM | standard cubic feet per minute |
| Shoreline Area | area of the site outside HCIM barrier wall adjacent to the Duwamish Waterway and Slip 6 |
| the site | the former Rhone-Poulenc facility located in Tukwila, Washington |
| SP | poorly graded sand |
| SU | standard pH units |
| TDS | total dissolved solids |
| TIC | total inorganic carbon |
| TSS | total suspended solids |
| UAZ | upper aquifer zone |
| Work Plan | *Revised $Co_2$ Neutralization Pilot Study Work Plan* (Amec Foster Wheeler, 2016a) |

# 1.0 Introduction

The former Rhone-Poulenc facility ("the site") is located adjacent to the Duwamish Waterway in Tukwila, Washington. This *Carbon Dioxide Neutralization Pilot Study Report* ("Report") was prepared to document the results of a *pilot study* conducted to assess the efficacy of carbon dioxide ($CO_2$) injection to neutralize portions of the site with groundwater exhibiting high pH. The pilot study was implemented based on the *Revised $CO_2$ Neutralization Pilot Study Work Plan* (the "work plan"; Amec Foster Wheeler, 2016a). Results from the pilot study will be used to complete the Corrective Measures Study (CMS) that is being performed to address the requirements of the Resource Conservation and Recovery Act Administrative Order on Consent No. 1091-11-20-3008(h) ("the Order").

A draft *Corrective Measures Study Work Plan* (AMEC, 2014) included a preliminary screening of remedial technologies to be included in the CMS for the site. The preliminary technology screening identified $CO_2$ injection as the preferred technology for neutralizing groundwater affected by high pH in the Shoreline Area of the site (Figure 1). This technology has a limited history of use; therefore, site-specific testing was needed to fully assess its applicability and to collect the detailed information needed to evaluate $CO_2$ injections as a component of the corrective measures' alternatives.

This report presents:

- Background information (Section 1);
- Pilot study objectives (Section 2);
- Pilot and bench-study methods (Section 3);
- Objective-specific results of the pilot study (Section 4); and
- Conclusions (Section 5).

The pilot study area is shown on Figure 1. A hydraulic control interim measure (HCIM) implemented at the site includes a low-permeability subsurface barrier wall, groundwater extraction system, and surface cover. The *HCIM Area* is the portion of the site enclosed within the barrier wall. The *Shoreline Area* is the portion of the site outside of the barrier wall adjacent to the Duwamish Waterway and Slip 6 (Figure 1). Elevated pH levels occur near the southwest corner of the site as a result of historical releases of sodium hydroxide (caustic) from a storage tank that was located in that vicinity. Injection of strong acid to neutralize the high pH could potentially adversely affect the adjacent surface water and site workers. As such, $CO_2$ was selected as the preferred chemical pH adjuster, as the mildly acidic gas would have limited effect on surface water and site workers if releases were to occur during injection.

## 1.1 Statement of the problem

As discussed in Section 3 of the CMS Work Plan, elevated pH levels have been observed in groundwater in the southwest portion of the site, both inside and outside the barrier wall (Figure 2). Figure 2 shows contours of pH levels at the site for all pH values greater than 8.5 standard units (SU). The vertical extent of pH levels that exceed 8.5 SU is shown on Figure 3 for cross sections along the Duwamish Waterway and Slip 6. The elevated pH values shown on Figures 2 and 3 are based on site groundwater monitoring results from March 2008 to February 2018 and data from the 2011 shoreline investigation (AMEC 2012). The contoured data on Figure 2 show that the area with elevated groundwater pH values greater than 8.5 SU is limited to the southwest corner of the site and includes a portion of both the HCIM and Shoreline areas. Figure 2 also shows that pH levels elsewhere on the site are near neutral and slightly acidic, as normally observed for groundwater in this area. As discussed in the CMS Work Plan and shown on Figure 3, the pH levels tend to be highest at depths ranging from approximately 30 to 60 feet below ground surface (bgs).

High pH groundwater and soil located within the HCIM Area have been effectively isolated from the environment and have limited potential to cause adverse impacts on human health and the environment for as long as the HCIM and surface cover are in place and functional. The area of elevated pH located in the Shoreline Area along Slip 6 and the Duwamish Waterway is not contained, high pH groundwater in this area may be in contact with the nearby surface water.

Because the area within the barrier wall is contained, the work plan focused on the areas within the Shoreline Area and enclosed by the contour line representing elevated pH greater than 8.5 SU. This area within the Shoreline Area enclosed by the pH 8.5 SU contour is defined as the "high pH target area" (Figure 2). This pilot study was performed in the area inside the barrier wall to limit potential adverse effects while performing the study. Results will be applied during the CMS to address the high pH target area.

A pH of 8.5 SU for areas to be addressed was selected based on surface water quality criteria for the Duwamish Waterway established by the Washington State Department of Ecology. Other contaminants are present in the high pH target area at concentrations exceeding their preliminary remediation goals (PRGs); neutralization of the high pH may be necessary to successfully remediate the other constituents of concern (COCs) in this area, particularly copper and other metals.

## 1.2 Pilot study area conditions

Site characterization work conducted to date is discussed in Sections 2 and 3 of the CMS Work Plan; routine groundwater sampling results are presented in the operations and maintenance report which are submitted annually. The hydrogeologic conditions in the HCIM Area and Shoreline Area are described briefly below, along with a summary of groundwater results for pH and other important groundwater constituents that may affect neutralization of high pH soil and groundwater. A more thorough description of these areas is provided in the CMS Work Plan.

### 1.2.1 HCIM Area

The barrier wall was installed in 2003 and functions to enclose contaminated soil and groundwater within the HCIM Area, where most of the site manufacturing and production operations occurred. The HCIM barrier wall is keyed into the silty Upper Aquitard. Since late February 2004, the mean groundwater level inside the barrier wall as measured in monitoring well MW-49 has been more than 1 foot below the mean groundwater level measured in DM-8, the downgradient control well located outside the barrier wall in the Shoreline Area. These measurements indicate that a constant, inward mean hydraulic gradient has been achieved and maintained for the HCIM Area. Groundwater is pumped from the HCIM Area at a rate of 2 to 4 gallons per minute to maintain the inward mean hydraulic gradient. The barrier wall and groundwater recovery system have effectively isolated groundwater within the HCIM Area from groundwater outside the barrier wall and beneath the aquitard underlying the HCIM Area. The surface cover for the HCIM Area limits infiltration of surface water. For more discussion on the hydrogeologic conditions of the HCIM Area, see Section 2 of the CMS Work Plan.

### 1.2.2 Shoreline Area

The Shoreline Area consists of the strip of land west of the HCIM Area along the Duwamish Waterway and south of the HCIM Area along Slip 6. The Slip 6 portion of the Shoreline Area extends to the Boeing property line along the north side of Slip 6. Groundwater flow in the Shoreline Area is essentially stagnant. The presence of the barrier wall along nearly the entire Shoreline Area means that groundwater cannot flow freely from the HCIM Area toward the adjacent surface water, as occurred prior to construction of the barrier wall. Therefore, tidal changes from the Duwamish Waterway and Slip 6 move the nearly stagnant water within the Shoreline Area up and down along this strip of land; surface infiltration from unpaved portions of the Shoreline Area infiltrate and drain to the surface water within the Shoreline Area soils. The presence of the barrier wall near the eastern end of the Slip 6 Shoreline Area results in groundwater entering Slip 6 near the southeast corner of the barrier wall. Additional discussion of groundwater conditions in the Shoreline Area is presented in Section 2 of the CMS Work Plan.

### 1.2.3 Groundwater chemistry data

This section describes groundwater data available that was used to develop the work plan. These data were used to develop a preliminary basis of design for a $CO_2$ injection system and assess potential changes in geochemistry resulting from $CO_2$ injections. Groundwater data have been collected at the site as part of several investigations and monitoring events since the mid-1990s. As noted above, pH data for groundwater collected since 2008 were used to delineate the high pH area (Figure 2 and 3); the more recent pH data were used to reflect current groundwater conditions. These data were taken from quarterly monitoring reports and routine monitoring since January 2008, the *Shoreline Soil and Groundwater Characterization Data Report* (AMEC, 2012), nonroutine sampling conducted in 2014, and sampling conducted immediately prior to pilot testing.

Table 1 summarizes the range of analytical data for pH, total alkalinity, and total silicon for existing groundwater monitoring wells located within the pilot study area and for wells MW-43 and MW-44, which represent monitoring wells with the highest historically observed pH values outside of the barrier wall. The pH data in Table 1 represent results of groundwater monitoring conducted since March 2008 through the September 2017. Total alkalinity and silicon are not included as part of routine quarterly monitoring. The total alkalinity and silicon data for MW-53 and MW-54 represent a single monitoring event conducted in 2014. The silicon and alkalinity data for MW-29 include both the 2014 monitoring event and four 2005 quarterly sampling events. For the wells outside the barrier wall (MW-43 and MW-44), the total alkalinity and total silicon data in Table 2 represent results from the 2005 quarterly monitoring events.

The data in Table 1 reflect the range of values expected for these key chemical parameters for groundwater within the area of elevated pH. Table 2 summarizes overall water chemistry data for the site. The data in Table 2 were taken from Round 28 groundwater monitoring conducted in June 2005; this monitoring event occurred after groundwater in the Shoreline Area had adapted to conditions after barrier wall construction and during the period of detailed groundwater chemistry monitoring.

Groundwater alkalinity and pH data were used to estimate how much carbonic acid would be required to neutralize groundwater in the high pH target areas. Adding an acid into site groundwater changes the chemical equilibria and results in the precipitation of solids. The high silicon concentrations in high pH groundwater were expected to cause precipitation of silica as the pH is reduced. Prior to pilot testing, the relationship between groundwater pH and silicon was modeled using groundwater data from monitoring well MW-44. The groundwater chemistry modeling results are discussed in detail the work plan; the model indicated that high pH groundwater at the site is saturated with amorphous silica. The model results indicated that approximately 1,300 milligrams per liter (mg/L) of solids, primarily consisting of amorphous silica, would precipitate from the addition of $CO_2$ to bring the MW-44 groundwater pH down to 8.5 SU. The precipitated solids could affect aquifer characteristics and cause fouling, which could affect follow-up injections in a fixed injection well.

## 2.0 Pilot study objectives

The purpose of the pilot study was to assess the effectiveness and feasibility of $CO_2$ injection to neutralize high pH groundwater to support evaluation of this technology in the CMS. The pilot study evaluated the technical feasibility of $CO_2$ injection to neutralize the high pH in the target area and evaluated factors affecting injection system design. The pilot study objectives were:

1. Estimate the amount of $CO_2$ that would be consumed to neutralize high pH groundwater and soil in contact with the high pH groundwater.
2. Assess $CO_2$ practical injection rates within the site.
3. Estimate the practical radius of influence (ROI) for $CO_2$ injection wells.
4. Evaluate the effect on the formation and collapse of groundwater mounding caused by injection of gaseous $CO_2$.
5. Evaluate the kinetics of high pH groundwater neutralization and pH rebound.
6. Evaluate the $CO_2$ utilization efficiency and $CO_2$ consumption required to neutralize high pH groundwater and soil in the field.
7. Evaluate potential changes in aquifer characteristics that may result from $CO_2$ injection.

Evaluate changes in geochemistry and other parameters that may result from $CO_2$ injection. These objectives and data quality objectives (DQOs) support evaluation of the potential effectiveness of $CO_2$ injection in achieving neutralization objectives and provide information needed for the conceptual design and cost estimating required to evaluate this remedial approach for neutralization of groundwater within the Shoreline Area in the CMS. A conceptual level design is necessary as part of the CMS for evaluation and selection of the preferred remedy for the site; the pilot study objectives and DQOs are sufficient to support the conceptual level design needed for the CMS. The pilot study results also provide information that could be used in full-scale design if the technology is determined to be feasible in the CMS.

## 2.1 Initial $CO_2$ consumption

The first objective was to determine the $CO_2$ demand required to neutralize a unit volume of both soil and water in the target area. Prior to $CO_2$ injection, the high pH groundwater was in equilibrium with the soil matrix. $CO_2$ injected into the pilot testing area dissolves into the groundwater as carbonic acid and neutralizes groundwater alkalinity, decreasing the groundwater pH and causing amorphous silica to precipitate onto the surfaces of subsurface soil. As the pH in the groundwater declines, an acid concentration gradient forms between the soil surfaces and the groundwater, resulting in diffusion of acid from the groundwater to the soil surfaces, where it would react with alkaline compounds on the soil. The extent to which this back diffusion occurs is based on different factors including the buffering capacity of the soil and soil specific surface area in contact with groundwater. It was expected that initially the acid-buffering capacity of the soil would be greater than the acid demand required to neutralize groundwater and as the injected acid was consumed by the soil buffering capacity, rebound in groundwater pH would be observed. Rebound in pH was expected to be slow relative to aqueous equilibria and mineral precipitation reactions; as such, several neutralization cycles were assumed to be required to fully neutralize the high pH soil.

The total dose of $CO_2$ needed to achieve full neutralization depends on the groundwater alkalinity and the soil buffering capacity. To achieve remediation of the high pH target area, both soil and groundwater need to be neutralized. The carbonic acid demand for groundwater may be readily and accurately determined from the measured groundwater alkalinity and concentrations of other constituents determined from sample analyses.

The soil buffering capacity is more complex and must be empirically evaluated in a laboratory to determine the total acid dose required to fully neutralize subsurface soils to achieve a defined groundwater pH. Together, the groundwater alkalinity, buffering capacities of representative soils, and quantities of the different soils within the high pH plume is used to determine the total amount of $CO_2$ required for neutralization.

## 2.2 $CO_2$ injection rates and injection pressures

The second objective was to determine the relationship between injection pressure and injection rate. This information is site specific and must be evaluated in the field. The second objective was to determine an optimal operating point for $CO_2$ injection to neutralize the high pH target area. The injection pressures needed to achieve a given $CO_2$ dose depend on aquifer and well characteristics, requiring site-specific measurements. As silica precipitates during neutralization, the injection pressures required to maintain a given injection rate had the potential to increase. The pilot study assessed these changes.

## 2.3 Radius of influence

The third objective was to determine the practical ROI for $CO_2$ injection wells; this information is site specific and was evaluated in the field to determine the number of wells needed to effectively remediate the high pH target area without adversely affecting areas with acceptable pH levels and to avoid loss of $CO_2$ to adjacent water bodies. The ROI is affected by injection rate and soil lithology and was measured for different gas injection flow rates. As the $CO_2$ injection flow rate is increased, the ROI was expected to increase, within limits. However, excessively high injection rates had the potential to create gas channels that would decrease the effective ROI, even though neutralization may be observed at greater distances from the gas injection location due to the formation of gas channels. The ROI evaluation only needs to provide a general understanding of the area addressed by injection in a single well; it is not necessary to accurately characterize the ROI, as it may vary with well location due to soil heterogeneity. The ROI will be used to determine the number of wells needed to neutralize the target area; the ROI for individual wells can be changed during operation by changing the injection flow rate. Additionally, if the actual ROIs in a full-scale system differ from that determined in the pilot study, injection wells can be added to fully address the target area without substantially increasing remediation costs.

## 2.4 Groundwater mounding

The fourth objective was to characterize groundwater mounding during and after $CO_2$ injection. Groundwater mounding was expected to occur during gas injection through the temporary displacement of groundwater in soil matrix pore spaces. The groundwater mound would form as the gas displaces the groundwater upward and laterally in the vicinity of the injection area. Once the gas had moved to the groundwater surface, the mound dissipates radially outward. When gas flow ceases, the gas-filled pores become re-saturated with groundwater and the mound collapses, resulting in a temporarily depressed groundwater table. Cycles of groundwater mound formation and collapse can create mixing conditions in the injection zone. Groundwater mounding was assessed by measuring groundwater elevations within the injection area. Only a general understanding of groundwater mounding and collapse characteristics is needed, as this is an operational parameter that can be controlled during injection operations. A general understanding is sufficient to assess this technology in the CMS and to estimate operation and maintenance costs.

## 2.5 Assessment of pH neutralization and rebound rates

The fifth objective was to assess pH neutralization and rebound rates; the rate of neutralization is balanced with the utilization efficiency of the $CO_2$ injected and the ROI to determine an optimal injection flow rate. The neutralization rate of the groundwater was expected to be a function of the $CO_2$ injection flow rate. The rate of neutralization was assessed using pH loggers placed in observation wells. The neutralization rate requires only general characterization, as it will be affected by variation in groundwater chemistry and soil types; full-scale neutralization of the high pH target area would include pH monitoring to assess actual neutralization rates and to control operations.

As discussed in Section 2.1, pH rebound was expected to occur after the pH of the groundwater had been initially reduced and $CO_2$ injection was stopped. Groundwater pH was expected to increase as the soil buffering capacity reacted slowly with the groundwater. The time scale for pH rebound was assessed in the pilot study to estimate the time required for neutralizing the high pH target area. The rate of pH rebound needs to be assessed in addition to any permanent pH decrease achieved by $CO_2$ injection. The pH rebound characteristics need only be generally characterized, as actual characteristics will likely depend upon actual soil type distribution in the target areas outside the HCIM area.

## 2.6 $CO_2$ utilization efficiency and consumption

The sixth objective was to estimate the $CO_2$ utilization efficiency. The utilization efficiency for $CO_2$ is the percentage of injected $CO_2$ that dissolves into groundwater and is available for neutralizing the groundwater and soil. It was expected that only a portion of injected $CO_2$ would dissolve into the groundwater; undissolved $CO_2$ would migrate to the surface and be released to the atmosphere. $CO_2$ utilization efficiency is important in determining the cost of injecting gaseous $CO_2$ into the subsurface for neutralization. It was expected that the utilization efficiency would be affected by the injection rate. As $CO_2$ is injected, the gas will follow preferential flow paths, such as high-permeability soils, natural or constructed surface vents, or debris in the ground, that may provide a conduit or barrier for the gas. High injection rates would likely cause channels of gas to form from the injection point to the vadose zone. It was expected that $CO_2$ gas bubbles would be present within the injection zone. These gas bubbles were expected to either slowly dissolve as $CO_2$ was utilized to neutralize soils, or they may coalesce and could move upward, toward the surface.

## 2.7 Changes in aquifer characteristics

It was anticipated that as groundwater was neutralized, amorphous silica (and possibly other silicates) would precipitate onto the subsurface aquifer soil matrix. This precipitation could impact the effective soil porosity and reduce aquifer permeability. Changes in aquifer characteristics would likely be variable and depend on factors such as initial pH, soil type, and overall groundwater quality. The effect could also be temporary. Due to the potential for variation, only a general understanding is needed to assess $CO_2$ neutralization as a potential remedy for the site. If substantial changes are noted in aquifer characteristics in the pilot study, the full-scale design can be adapted to address the changes.

## 2.8 Changes in groundwater and soil chemistry

Characterization of the soil and groundwater changes resulting from injection of $CO_2$ provides insight into the groundwater/soil systems' response to changes in pH that may affect ongoing injection operations and attainment of neutralization objectives. The pilot study included groundwater sampling analysis before and after groundwater neutralization to assess water chemistry changes caused by $CO_2$ injection. The groundwater analyses were used to support and assess equilibrium modeling for system analysis. The results from the pilot study were expected to be confirmed by equilibrium modeling, allowing the equilibrium model to be used in the future to accurately predict the effect of neutralization on groundwater chemistry and the potential for precipitation of dissolved components.

# 3.0 Pilot study implementation and observations

The pilot study was implemented in accordance with the methods described in the work plan with the variations described below. A summary of test methods and key observations or data that impacted pilot testing methodology are described in this section. Each component of the pilot study and how the data collected during the pilot study was used to achieve these objectives is summarized in Table 3 and related to the DQOs discussed in Section 2.0.

## 3.1 Pilot testing location

Pilot testing was conducted inside the barrier wall to reduce the potential for adverse impacts to adjacent surface water that could occur during injections in the Shoreline Area. This location supported a lower risk evaluation of a wider range of conditions than could be evaluated in the Shoreline Area. Groundwater chemistry and soil composition within the high pH areas inside the barrier wall were assumed to be similar to conditions within the Shoreline Area outside the barrier wall based on proximity of MW-53 (inside the barrier wall) to MW-43 and MW-44 (outside the barrier wall) and based on comparing pH results for MW-53 to the pH results for MW-43 and MW-44 (Table 1 and Figure 2). The area near well cluster MW-43/MW-44 in the Shoreline Area contains some of the highest pH levels observed historically at the site (Figure 2).

Pilot testing was conducted using a new gas injection well installed approximately 7 feet forth-northwest of MW-53 and 10 feet northwest of MW-54; this new injection well was located directly across the barrier wall from wells MW-43/MW-44 and the high pH target area (Figure 2). The injection well was also located approximately 20′ from the barrier wall, which allowed the effects of the barrier wall on $CO_2$ injection to be evaluated; this location is similar to and mirrors the likely injection locations within the high pH target area located outside the barrier wall based on anticipated ROI and proximity of the barrier wall to Slip 6. The high pH target area located outside the wall is also largely covered with an asphalt cover, although a portion of the Shoreline Area (located immediately along the shoreline) has vegetative cover (Figure 2).

## 3.2 $CO_2$ injection, observation, and vent well installation details

One new injection well, seven new monitoring wells, and one vent well were installed near existing wells MW-53, MW-54, and MW-29 for the pilot study. The layout of the pilot study wells is shown on Figure 4. Figure 5 presents cross sections across the pilot study area. Table 4 presents a list of the existing and new wells installed for the pilot study, as well as the well depth, screen interval, and initial groundwater pH. Table 4 shows that the groundwater pH in the deeper wells in the pilot study area prior to injecting $CO_2$ was greater than that in MW-43/44.

### 3.2.1 Aquifer zones

In the pilot testing area, the water table is approximately 15 to 17 feet bgs. Testing was conducted in the shallow aquifer bounded by the silty Upper Aquitard, which is approximately 50 feet bgs near MW-53/54. The shallow aquifer consists of two aquifer zones in the area where pilot testing was conducted:

- Upper aquifer zone (UAZ)—The UAZ consists of poorly graded sand (SP) and extends to a depth of 43 to 45 feet bgs.
- Lower aquifer zone (LAZ)—The LAZ consists of silt and silty sand (ML-SM) and is between 43 and 50 feet bgs. The LAZ is directly above the Upper Aquitard.

### 3.2.2 $CO_2$ injection well

$CO_2$ was injected into a new injection well (Figure 4) during testing. The new injection well was screened within soil types similar to those for well MW-43, which is located outside the barrier wall and within the high pH target area. The depth of the 5-foot injection well screen was selected to target the silty sand within the LAZ; the bottom of the screen was placed at the top of the silt aquitard the barrier wall is keyed into. The injection well construction details are provided on Drawing 1 and in Table 4.

The injection well was drilled with a sonic drill rig to maximize the soil recovered to be used for bench-scale testing of soil buffering capacity. Soil samples were collected from the injection well boring and tested for soil pH beginning at approximately 35 feet bgs and extending to the bottom of the boring. Soil pH was measured with a calibrated, portable pH meter by placing a small amount of soil in a container and hand mixing with a 1:1 dilution of deionized water. The initial groundwater pH encountered in the field during well installation was approximately 12 SU, which is greater than the pH encountered outside of the barrier wall and indicated that the proposed injection well location would be suitable for pilot-scale testing.

Soil samples for bench testing were collected from the injection well boring for further testing. Drawing 2 shows the configuration of the $CO_2$ injection system. The $CO_2$ injection system was located near the injection well and its components were solar powered and/or were powered using a portable battery. Aboveground pressurized piping for the $CO_2$ injection system consisted of high-density polyethylene (HDPE) and galvanized steel. A manual shutoff valve and pressure relief valve were located at the wellhead for the injection well, as shown on Drawing 2. Figures 6, 7 and 8 show annotated pictures of the $CO_2$ injection system.

The wellhead for the injection well was constructed to allow the well to be pressurized with $CO_2$ for injection. A schedule 80 polyvinyl chloride (PVC) adapter was glued to the schedule 80 PVC well casing to accept threaded galvanized steel fittings. Teflon tape was used to seal all threaded joints. Gas-tight compression fittings were used to run tubing or instrument cables into the wells. All materials selected for the injection system were confirmed to be compatible with $CO_2$ and were able to safely contain expected pressure and flow ranges.

### 3.2.3 Observation wells

Existing groundwater monitoring wells MW-29 (approximately 31 feet from the injection well) and MW-53/MW-54 (approximately 7-10 feet away from the injection well) were used as observation wells during the pilot study. In addition, seven new observation wells, or injection monitoring wells (IMWs), were installed at varying distances and depths to monitor the ROI, $CO_2$ utilization efficiency, groundwater mounding, and changes in groundwater chemistry (Table 4 and Figure 3).

All observation wells were used to collect data for the pilot study. Drawing 1 shows the construction details for the new observation wells and Drawing 2 shows the piping and instrumentation details for the new and existing observation wells for the pilot study. Figure 9 shows a photograph of the manifolds installed on the observation wells. The manifolds included a hand valve to allow for wellhead pressure to be monitored using a digital manometer or pressure transducer, a sampling port, and a gas-tight compression fitting for a transducer cable.

Table 4 summarizes the approximate depths of the observation well screens relative to the injection well, the approximate spacing between the observation wells and the injection well, and the initial groundwater pH of the new observation wells. Well boring logs are presented in Appendix A.

The new observation wells were installed with 2-inch schedule 80 PVC screened over a 10-foot interval, except for the deeper ("D") observation wells at points "A1," "B1," and "A2," which were screened over a 5-

foot interval within the ML-SM unit. The observation wells were completed with flush, heavy-duty surface mounts.

The locations of observation wells IMW-A2-S, IMW-A2-D, and IMW-B2-S were changed from what was presented in the work plan due to refusal while drilling. IMW-A2-S, IMW-A2-D, and IMW-B2-S were moved to the east of the injection well, however their radial distance from the injection well did not change from what was proposed. MW-54 was screened in the silt aquitard below the LAZ, and part of the well sand pack extends into the overlying LAZ by approximately 2 feet.

### 3.2.4 Vent wells

The pilot study design included one new vent well that was designed to vent $CO_2$ passing through the vadose zone. Drawing 1 shows the construction details for the new vent well and Drawing 2 shows the instrumentation for the vent well. Figure 4 show the location and layout of the vent well in relation to the injection and observation wells. Table 4 summarizes the approximate depths of the vent well screen relative to the injection well and the approximate spacing between the wells. The new vent well has a 15-foot screen length that was placed so that it expands partially into the top 10 feet of the groundwater table. For Phase 1 and Phase 2 of the pilot test, the vent well had a logging pH and temperature probe, which provided pH and temperature data at the top of the saturated zone near the injection well. The new vent well was constructed with a 2-inch schedule 40 PVC casing. The top of the vent well was mounted flush to the existing pavement surface, similar to existing groundwater monitoring wells. A threaded cap was installed on the vent well casing. A manifold was installed which included a hand valve to allow for wellhead pressure to be monitored using a digital manometer or a pressure transducer, a sampling port, and a gas-tight compression fitting to run a transducer cable.

### 3.2.5 Well construction details

All new wells were drilled by Cascade Drilling, who is licensed in the State of Washington. Observation wells were installed using direct-push technology, and the new injection well was installed using a sonic drill rig under the supervision of a geologist. A private utility locate was hired to locate subsurface utilities in the area of the proposed drilling location prior to drilling.

The injection well boring was continuously logged to a depth ending at the silt aquitard for lithology and for collection of soil samples for bench testing. The observation well borings were backfilled to the target well depth using medium bentonite chips. The injection well boring was backfilled with bentonite grout slurry. Drill cuttings from the well installations were logged then directly placed into drums and labeled with the contents and date. The drill cuttings were sampled using U.S. Environmental Protection Agency (EPA) Method 5035 and analyzed using EPA Method 8260C and EPA Method 6010C for volatile organic compounds and metals (respectively). Toluene concentrations resulted in a U220 waste classification. A contained in determination for these soils was received by the Washington State Department of Ecology, and soils were sent to Republic Services Roosevelt Regional Landfill for disposal.

A heavy-duty flush surface monument was cemented in place for each new well; the lids were removed to allow installation of the surface manifold piping needed to conduct the pilot testing. After pilot testing was complete, the surface manifold piping was removed, and the surface monument was sealed to protect the wells. The new wells were surveyed for location and elevation. The observation and injection wells were developed prior to use in the pilot study; recovered groundwater was confirmed to have a pH of less than 10 SU and then treated in the groundwater pretreatment plant prior to discharge to the Seattle sanitary sewer system.

## 3.3 Aquifer slug testing

Aquifer slug testing was performed before and after the pilot study to assess potential changes in aquifer permeability characteristics due to $CO_2$ injection. Testing was performed following the construction and development of the new injection and observations wells. Slug testing was performed to measure the average hydraulic conductivity of the formation surrounding the new injection well, existing monitoring wells MW-53 and MW-54, and well IMW-A1-D. These wells were selected because they are located nearest to the center of the $CO_2$ injection area and were expected to be the most highly affected by $CO_2$ injection.

Prior to slug testing, the initial depth to water was measured and recorded from the top of the well casing in each of the four slug test wells. An unvented water level transducer was placed within each well to record water levels during slug testing. The length of the cord use to suspend the transducer/logger was measured prior to installation, and the initial depth-to-water measurement was used to check the accuracy of the water level transducer readings. An In-Situ BaroTROLL data logger was used to record barometric pressure to compensate the well transducer readings for atmospheric pressure. The water level transducers were placed into each well and lowered to just above the bottom of the well. The water level transducers were set to record on an interval of 0.5 to 30 seconds, depending on the well.

Each slug test consisted of a falling-head phase and a rising-head phase. During the falling-head (or slug-in) phase, a 1.5-inch-diameter, 4-foot-long, solid PVC rod or slug filled with sand and sealed was quickly lowered into the well with a rope affixed to the top of the slug by hand so that it was completely submerged. The slug was inserted to minimize disturbance of the transducer/logger and its cable. The rise in water level resulting from displacing water in the well was monitored both by the transducer/logger and by manual water level measurements. After the water level became stable (defined as less than a 0.1-foot change in readings within 10 minutes), the slug was quickly removed from the well by hand to initiate the rising-head (or slug-out) phase. This phase was complete when the water level returned to its initial, pre-test, level or became stable using the same criteria as for the falling-head phase. In addition to transducer data, field personnel recorded depth-to-water measurements and time until the water levels stabilized.

A summary of slug test conditions is presented in Table 5. Wells screened in the LAZ and aquitard had a greater initial displacement than MW-53, which is screened in the UAZ. Slug testing results were analyzed using AQTESOLV software to estimate the hydraulic conductivity of the aquifer materials near the screens of the four wells that were tested using the inputs provided in Table 5, assuming an unconfined aquifer and using the Bouwer-Rice slug test method.

## 3.4 Bench-scale studies

Bench-scale studies were conducted to support final design of the pilot study using samples collected in the field during pilot testing well installation. Testing was performed to assess neutralization of pH-affected groundwater and soil. The objectives of the bench-scale studies were to measure the total acid demand for the groundwater and soil in the target areas, assess changes in groundwater chemistry caused by groundwater neutralization, evaluate temperature effects of neutralization, and verify the chemical equilibrium modeling. A groundwater study (Section 3.4.1) and a soil study (Section 3.4.2) were conducted.

### 3.4.1 Groundwater chemistry bench study

Two groundwater samples were collected from the new injection well using a peristaltic pump and dedicated tubing after well development. One groundwater sample was field filtered and analyzed for total dissolved solids (TDS) and dissolved silica. Another water sample was collected in a zero-headspace container for laboratory testing. The following field parameters were measured during sample collection: pH, turbidity, conductivity, redox potential, dissolved oxygen, and temperature. An aliquot was collected from the water sample container and analyzed for total suspended solids (TSS) and alkalinity.

A second 1,000-milliliter (mL) aliquot was also taken from the container and mixed and titrated with sulfuric acid from the initial pH of 11.62 SU to a pH of 6.49 SU. An endpoint of 6.49 SU was selected at this was likely to be the lowest observed pH in the injection target zone based on injection pressure and carbonic acid solubility. During the titration, the temperature of the groundwater increased 1.9 degrees Celsius (°C). The titrated sample was continuously mixed for 24 hours using a magnetic stir plate and then analyzed for dissolved silica, TSS, and alkalinity.

Results of the titration and sample analysis were compared to theoretical modeled dosage of $CO_2$ required to neutralize groundwater presented in the work plan (Section 4.1). The results were then used to adjust the estimated $CO_2$ mass loading to meet neutralization objectives during Phase 3 testing.

### 3.4.2 Soil buffering capacity study

This section describes bench-scale soil buffering capacity testing performed using soil and groundwater samples collected during installation of the new injection well described in Section 3.2.2. The buffering capacity was assessed by mixing soil samples with deionized water and reagent-grade sulfuric acid.

Two soil types were tested: an SP sample, which was collected from soil 30 to 35 feet bgs in the UAZ, and an ML-SM sample, which was collected from 43 to 48 feet bgs in the LAZ. The samples were initially mixed with deionized water to measure soil pH to confirm pH was above 10.5 SU as this was the criteria established to determine acceptable location of the injection well. The soil pH values of the SP and ML-SM samples were 10.97 SU and 11.54 SU, respectively.

For each soil sample, gravel and other debris larger than 0.25 inch was separated. Each sample was oven-dried at 70°C with periodic mixing until a change in weight of less than 1 percent was observed over 1 hour of consecutive readings. This was done to remove moisture and create a homogeneous sample for each of the two soil samples. Each soil sample was then thoroughly mixed to prepare a homogenous sample. The two crushed and dried soil samples were then tested for soil buffering capacity.

The soil buffering capacity test was completed in two stages. The first stage consisted of coarse testing to characterize the approximate soil buffering capacity. The second stage consisted of a finer resolution test based on first stage testing results. Some of the second stage tests also assessed the effect of site groundwater on the test results.

#### 3.4.2.1 Stage 1a

For the first stage, it was assumed that the total soil buffering capacity of each soil sample was approximately 20 times the total alkalinity of the groundwater in equilibrium with the soil, as measured in groundwater samples collected in the vicinity of soil samples (e.g., a groundwater alkalinity of 1,000 parts per million calcium carbonate [$CaCO_3$] equivalents would result in a maximum estimated soil buffering capacity of 2 percent by weight [$CaCO_3$ equivalents]). The first stage tested buffering capacity of soils by dosing 0, 5, 10, 10, 15, 20, and 25 times the groundwater alkalinity by weight, in order to estimate the maximum buffering capacity to be used in the second stage of testing. The following test procedure was used:

1. A total of six aliquots, each with approximately 5 grams of soil, were prepared from both soil types for a total of 12 aliquots to be tested.
2. The test series for each type of soil included six aliquots dosed with deionized water and reagent grade sulfuric acid at 0 (blank sample), 5, 10, 15, 20, and 25 (acid equivalence as $CaCO_3$ by mass)

times the alkalinity measured in groundwater from the injection well. Each aliquot had a total volume of 100 mL.

3. The aliquots were mixed on a shaker plate for 1 hour.
4. The pH in each aliquot was measured to obtain a baseline pH.
5. Each aliquot was continually mixed using a shaker for four days, after which the pH in each aliquot was measured.
6. The samples were mixed for an additional 24 hours and the pH of all six aliquots for each soil type were measured again. This process was repeated until a change of less than 0.1 SU was observed in all six aliquots for each soil type.

On day five, the pH measured in all aliquots except for the blank was within 0.1 SU of the pH measured on day four. The pH measured in every aliquot that contained acid was less than 2.0 SU, indicating that the soil buffering capacity was exhausted in less than 4 days. The aliquots containing the blanks and the lowest acid dose (five times the injection well groundwater alkalinity) were allowed to mix for an additional 13 days to verify observation and confirm that kinetics were not much slower than originally anticipated; additional pH measurements were recorded on day 11 and 18.

#### 3.4.2.2 Stage 1b

Stage 1b of the soil buffering capacity study consisted of the same procedure as Stage 1a (Section 3.4.2.1); however, the acid doses corresponded to 0.5, 1, 2, and 3 times the groundwater alkalinity in the injection well. Both soil types were tested in Stage 1B testing. Samples were mixed on the shaker for 11 days, with pH measurements taken on days 1, 4, 6, and 11. The highest pH measured (3.69 SU) was from the ML-SM soil at an acid dose corresponding to 0.5 times the groundwater alkalinity in the injection well. This dose was used as a maximum dose for Stage 2 soil buffering capacity testing.

#### 3.4.2.3 Stage 2

Stage 2 of the soil buffering capacity study tested a larger quantity of acid doses and used a dose corresponding to 0.5 times the groundwater alkalinity in the injection well as the maximum dose. A total of 21 acid doses for each soil types were tested during Stage 2 testing to more accurately determine the soil's buffering capacity. Seven duplicates for each soil type were performed for reproducibility. Four duplicate samples containing groundwater in the place of deionized water were tested at acid doses corresponding to 20, 40, 60, and 80 percent of the maximum dose obtained in stage 1b in addition to the quantity required to neutralize the groundwater to a pH of 6.5 SU. The results from the samples with groundwater added were used to assess the effect of groundwater on neutralizing the soil and the potential reduction in measured soil buffering capacity as a result of silica precipitation.

The following test procedure was used:

1. A total of 32 aliquots, each with approximately 5 grams of soil, were prepared from each crushed, dried soil sample (64 aliquots total for the two soil types).
2. Twenty-one of the soil sample aliquots for each soil type were prepared for the primary soil buffering capacity testing. The test series included one blank sample where no acid was added and 20 aliquots with equal incremental amounts of acid up to the maximum dose (the Stage 1b acid dose corresponding to 0.5 times the groundwater alkalinity in the injection well).

3. Seven aliquots for each soil type were prepared as a duplication of the primary test series. The duplicate series consisted of one blank duplicate sample and six duplicates at 10, 30, 50, 70, 90, and 100 percent of the maximum acid dose for Stage 2 testing.
4. Four aliquots mixed with site groundwater collected from the injection well instead of deionized water. The acid dose for these aliquots included the corresponding volume of acid to reduce the groundwater pH to 6.5 SU, based on the groundwater alkalinity titrations plus 20, 40, 60, and 80 percent of the maximum acid dose for Stage 2 testing.
5. Each aliquot was mixed with equal volumes of deionized water or a mixture of deionized water (or site groundwater, in the case of the four duplicates described in 3b) and standardized reagent grade sulfuric acid, so that the volumes of the water/acid mixture was 100 mL total. For the primary and duplicate/groundwater test series, each aliquot was dosed with standardized reagent grade sulfuric acid to evenly span the estimate range of the soil buffering capacity, with aliquots dosed from 0 to 100 percent of the maximum acid dose for Stage 2 testing.
6. Samples were mixed for 1 hour and then the pH of each aliquot was measured to obtain a baseline pH.
7. Each aliquot was continually mixed using a shaker for four days.
8. On day 4, the pH of 5 of the 21 aliquots for the primary series for each soil was measured.
9. On day 5, the pH of all aliquots was measured.

After 5 days, the 24-hour change in pH was less than 0.1 SU; therefore, testing was concluded. The final pH measurement of each of the aliquots and the initial acid doses were evaluated to develop a buffering capacity curve for each soil type. The buffering capacity of the soil was used to identify the total acid dose needed to fully neutralize the soil. This information was needed to estimate the total amount of $CO_2$ that must be delivered by an injection system (Section 4.1).

## 3.5 Field pilot study testing

The field pilot study test plan was designed to address the objectives discussed in Section 2.0. Testing consisted of injecting gaseous $CO_2$ into the injection well and observing changes in pressure, water levels, pH, temperature, and groundwater chemistry in the observation wells. These data were used to assess the ROI and to evaluate potential impacts of $CO_2$ neutralization on groundwater quality. Pilot testing consisted of four phases:

1. Phase 1: Assess the relationships for injection pressure, injection rate, and ROI;
2. Phase 2: Assess initial pH rebound;
3. Phase 3: Perform constant-flow injection at the optimal rate and pulsed operation to assess anticipated full-scale operating conditions; and
4. Phase 4: Assess long-term pH rebound.

Samples during field testing were collected as described in in Table 6 for the $CO_2$ injections and during pH rebound monitoring to compare neutralized water analyses to the baseline lab results and to the groundwater bench-study testing results. In general soil and groundwater samples were collected in accordance with the 2016 Quality Assurance Project Plan (QAPP) (Amec Foster Wheeler, 2016b) but did not follow all the requirements of the QAPP, such as the requirements for data validation and field duplicates.

Prior to initiating field testing, baseline groundwater chemistry and characterization samples were collected from the injection well, the observation wells (including monitoring wells MW-53/MW-54 and MW-29), and the vent well, which has a screen that extends beneath the water table. IMW-A2-S, IMW-B2-S, and IMW-A2-D were erroneously sampled for sulfide during baseline groundwater sampling. Samples collected from MW 53, MW-54, IMW-A1-D, and the injection well were analyzed for some select metals. These wells with the addition of the vent well were also sampled for sulfide, and the cations and anions listed in Table 6. These samples provided a baseline for water chemistry and concentrations of site metals anticipated to be affected by the neutralization of site groundwater for comparison to samples collected after $CO_2$ injections.

### 3.5.1 Phase 1: evaluation of injection pressure and flow rates

The initial phase of injection testing evaluated a range of injection pressures, the corresponding injection rates, and the resulting effect on the ROI for the injection well, and groundwater mounding resulting from injections. Additionally, groundwater mounding in the vicinity of the injection well was assessed. According to the *In-Situ Air Sparging Engineer Manual* (United States Army Corps of Engineers, 2013), injection pressures should range between the minimum injection pressure, (i.e., the sum of the hydrostatic pressure at the top of the well screen and the formation entry pressure) and the maximum injection pressure that does not cause fracturing of the subsurface soils. For the site, the minimum pressure to inject into the new injection was approximately 17 pounds per square inch gauge (psig), and the maximum injection pressure (including a safety factor of 20 percent) was approximately 28 psig (calculations are presented in the work plan). Initial injection testing assessed this pressure range.

The injection pressure was adjusted incrementally from 18 psig to 28 psig in five increments (18, 20, 23, 26, and 28 psig) and the flow rate for each test run, as measured by flow meter FM-1, was used to indicate the flow rate and also totalize the $CO_2$ gas flow. A Thermal Instrument Model 600-9 Thermal Mass Flow meter was used. The Work Plan specified an initial injection gage pressure of 17 pounds per square inch (psi); however, 18 psi was used due to an error by field staff.

Each injection pressure tested had a corresponding injection flow rate that is dependent on well and aquifer characteristics. Injection pressures for $CO_2$ were controlled by manually adjusting the pressure regulator and flow regulating needle valve shown on Drawing 2. The injection well was pressurized with $CO_2$ by opening hand valves HV 2-1 (or HV 2-2), HV 3-1 (or HV 3-2), HV 4-1 (or HV 4-2), and then HV-5 on the injection well inlet, as shown on Drawing 2. The $CO_2$ injection pressure was adjusted by manually setting the pressure regulator (PR-1 or PR-2) and the flow-regulating needle valve, which maintained a constant injection pressure.

Between the second and third injection events, the following changes were made to the $CO_2$ injection system to allow a constant pressure to be maintained without exceeding the flow meter capacity (note that these changes are reflected on Drawing 2):

- Increased the diameter of the hose from ½-inch to ¾-inch to reduce the pressure drop between the $CO_2$ injection manifold and the injection well-head manifold.
- Moved the flow regulating valve from the $CO_2$ injection manifold to the injection wellhead manifold to reduce the pressure drop associated with the $CO_2$ injection manifold.

Between the third and fourth injection events, the following changes were made to the $CO_2$ injection system (note that these changes are reflected on Drawing 2):

- A manual pressure relief valve was added to the injection wellhead manifold so that the $CO_2$ injection manifold could be purged after injection events.

- PR-1, which had a maximum pressure of 35 psi, was replaced with a pressure-regulating valve that has a maximum pressure of 75 psi to allow a constant pressure to be maintained without exceeding the flow meter capacity.

Wellhead pressure was monitored using a digital manometer or pressure transducer to support evaluation of the ROI for each injection pressure being tested; digital manometer readings were taken every 15 minutes during active injections and once 15 minutes after concluding the injection event. MW-53 and IMW-A2-S were equipped with pressure logging transducers to monitor wellhead pressure during and after injection events. This was done to determine how long it takes for the pressure and water levels to decrease during the groundwater mound collapse and reach a steady-state value, implying that the effects of groundwater mounding created by gas injection have dissipated. Each observation well was equipped with a transducer installed beneath the water level to measure and record water levels in order to evaluate groundwater mounding.

It was anticipated that the pressure and water levels in the observation wells located within the ROI would increase after injection startup, approach a semi-steady state, and then subside after gas channels had reached the vadose zone. Injection events were set to last until either a decline in pressure and water levels was observed in the observation wells for a continuous period of 30 minutes or until approximately 3:30 PM (site security constraints limited site activity from 8:00 AM to 4:30 PM). Once the constant pressure run was complete, the $CO_2$ feed to the injection was closed and the system remained turned off for 24 hours to allow excess $CO_2$ trapped in the aquifer to dissipate or dissolve. Note that in all injection events the injection was stopped around 3:30 PM as the water levels in all wells did not decrease for a period of 30 minutes.

Table 7 summarizes each of the Phase 1 injection events. Injection dates were spread out to allow excess $CO_2$ trapped in the aquifer to dissipate or dissolve, groundwater sampling to occur, and system modifications to be made. In addition, weekend work was not permitted for site-security reasons causing additional delays between injections. During injection events 2, 4, and 5, the total flow of $CO_2$ exceeded the capacity of the flow meter. This caused the value displayed on the flow meter's totalizer to be inaccurate. The $CO_2$ flow rate did not exceed the capacity of the flow meter during injection event 3 due to the adjustments made to the $CO_2$ injection system discussed above. The average $CO_2$ flow rates and mass of $CO_2$ injected presented in Table 7 were calculated from changes in level of the bulk $CO_2$ tanks; changes were recorded by the tank's telemetry unit, which took hourly measurements. The injection volumes calculated using the tank level were compared to the flow meter's totalizer data for injection events 1 and 3, where the flow rate did not exceed the flow meter's capacity, and the difference was found to be 3 and 14 percent, respectively. This comparison demonstrates that changes in tank level can be used to approximate the $CO_2$ injection flow rates when the capacity of the flow meter is exceeded.

The pressure and water level measurements logged in the observation wells were used as one indicator of the ROI and to determine optimal injection periods for pulsed operations (as defined by the increasing water levels and pressures in the observation wells). Groundwater pH and temperature in the wells were also monitored using transducers, and the results were used to support evaluation of the ROI. The groundwater temperature logger was used to assess the potential for exothermic effects during $CO_2$ injection.

At the conclusion of each injection pressure test run (i.e., after pressure and groundwater mounding in the observation wells had dissipated), groundwater samples were collected from each observation well and the vent well and analyzed in the field for field parameters—pH, temperature, turbidity, conductivity, dissolved oxygen, and redox potential—and in the laboratory for total alkalinity, dissolved total inorganic carbon (TIC), TDS, and dissolved silica. In addition, at the end of Phase 1 testing, samples from observation wells were analyzed for TSS and samples collected from MW 53, MW-54, IMW-A1-D, the injection well, and the vent well were analyzed for sulfide, and the cations and anions listed in Table 6. Results for pH, alkalinity, and TIC were used to assess the ROI for the injection pressure/flow rate tested. Results for TDS, TSS, and dissolved silica were used to assess precipitation caused by neutralization of the high pH groundwater.

The effects of the different injection flow rates on $CO_2$ losses to the vadose zone were assessed by measuring changes in groundwater TIC. The approximate mass estimates for $CO_2$ delivery and dissolution were used to estimate the mass of $CO_2$ lost (in pounds) per pound of $CO_2$ delivered to the aquifer, as measured at the injection system manifold. The utilization efficiency was calculated as the percentage of $CO_2$ delivered to the aquifer and available for neutralization of the groundwater (i.e., the total quantity of $CO_2$ dissolved into groundwater as measured by TIC analyses) divided by the total mass of $CO_2$ injected. Injection flow rates that maximized the $CO_2$ utilization percentage and yielded an acceptable ROI were considered optimal.

Results of Phase 1 testing are described in Section 4 and identified the following optimized testing parameters to be assessed during Phase 3 testing:

- Initial injection pressure of 26 psi, adjusted throughout the injection to maintain a constant flow rate of 19.8 SCFM;
- An injection cycle of 2 hours of $CO_2$ injection followed by 1 hour of rebound time;
- Three cycles per day.

### 3.5.2 Phase 2: pH and water chemistry monitoring

Upon completion of the Phase 1 injection testing, pH rebound was monitored during Phase 2. The pH rebound and changes in groundwater chemistry resulting from re-equilibration with the soil matrix were assessed by monitoring pH in observation wells, the injection well, and the vent well and by collecting groundwater samples at the end of Phase 2. Rebound was considered complete when the pH in IMW-A1-D, IMW-A2-D, the injection well, and MW-54 increased to 10 SU or greater. Bench-testing indicated that the soil had minimal buffering capacity and the pH may never rebound to 10 SU, therefore a second criteria was established. The second criteria was to consider rebound complete once the rate of change of groundwater pH in these wells was less than 0.2 SU over a period of four consecutive weeks. A pH of 10 SU was selected as wells MW-53/MW-54 have had historical pH measurements between 10 and 11 SU.

Samples collected from MW 53, MW-54, IMW-A1-D, the injection well, and vent well were analyzed for sulfide, metals, and the cations and anions listed in Table 6. In addition, pH and temperature were monitored to assess pH rebound and temperature changes from re-equilibrium of the neutralized groundwater with site soils. The data collected from the transducers were used to assess the rate of pH rebound and to determine when rebound monitoring should be terminated to proceed with Phase 3 injection testing.

A summary of the pH changes during groundwater monitoring in Phase 2 is presented in Table 8. The pH in every monitoring well stabilized, except for in IMW-B1-S and MW-54. The pH in MW-54 steadily increased during Phase 2. Review of the boring logs for MW-54 indicated that the well was screened in the silt aquitard and that part of the well sand pack extends into the overlying LAZ by approximately 2 feet. The steady increase in pH after the last injection was likely due to back-diffusion of higher pH groundwater into MW-54 from the silty aquitard unit. The transducer was removed, as the data were not likely representative of pH rebound kinetics given the location of the well screen in the aquitard.

The pH and temperature in IMW-B1-S fluctuated around 7.7 SU; the pH briefly increased to approximately 9.0 SU twice during Phase 2, however the water level did not change.  The groundwater pH in IMW-A2-S, which is also screened from 25 to 35 feet bgs, also appeared to fluctuate. The changes in groundwater pH observed in IMW-A2-S and IMW-B1-S appeared to fluctuate tidally, however water level remained constant. Both of these wells are screened just above the high pH groundwater area, suggesting the vertical displacement of groundwater; the mechanism associated with this displacement of high pH groundwater could not be determined.

### 3.5.3 Phase 3: full scale operations simulation

Phase 3 field testing consisted of full-scale injection simulations at the optimum injection rate, as identified from Phase 1 testing. Prior to the initiation of Phase 3 testing, results from Phases 1 and 2 and the final details for the Phase 3 testing plan were summarized in a technical memorandum submitted to EPA (Wood 2018) with authorization to proceed with Phase 3 testing provided by EPA via email on November 5, 2018.

The Phase 3 injection simulation included testing pulse injections (i.e., periodic, constant flow injections) to promote mixing and $CO_2$ distribution in the injection zone. Phase 3 testing consisted of injecting at the target flow rate determined from the Phase 1 testing. Changes in injection pressure required to maintain constant flow were expected to indicate changes in aquifer characteristics (e.g., an increase in required injection pressure to maintain a given injection rate may indicate aquifer plugging due to precipitation in the injection well sand pack or aquifer formation).

The objective of the Phase 3 injection simulations was to create conditions where the groundwater would mix due to cycles of groundwater mounding followed by groundwater mound collapse. This was done through pulsed $CO_2$ injections, whereby the $CO_2$ flow was periodically cycled on and off. The flow of $CO_2$ was set to the appropriate injection cycles manually. The $CO_2$ flow rate was controlled through adjustments to the pressure regulator valves and the flow-regulating needle valve. Injection pressure for the injection well was monitored throughout this phase of testing to assess changes in injection pressure for maintaining the target $CO_2$ flow rate. Pressures measured in the injection well and the other observation wells were used in conjunction with water levels and pH measurements in the observation wells to fine-tune injection cycling during Phase 3.

Injection cycling during Phase 3 testing was initially designed to continue until the pH measured in the adjacent observation wells reached approximately the site background pH (e.g., the average value for wells outside of the affected high pH areas) or 6.5 SU. A pH of 6.5 SU was initially selected because this value is close to the site background pH and the proximity of this pH to the first dissociation constant for carbonic acid (i.e., $pK_1 = 6.3$). During Phase 3 testing, the target pH was adjusted to 8.5 SU because this pH is optimal for metals stabilization after $CO_2$ injection and is within the range of normal pH for the Duwamish Waterway. In addition, only the areas within the pH 8.5 contour within the Shoreline Area presented in Figure 2 are to be addressed in the CMS. IMW-A2-D and IMW-A1-D were used to determine whether the neutralization target pH was obtained. The EPA approved of the revised pH target via email on December 19, 2018.

Table 9 summarizes the Phase 3 injections. Phase 3 injections began on November 12, 2018. A total of 21 injection events were performed during Phase 3 testing, consisting of 61 two-hour injection cycles. After the 21st injection event, the pH measured in IMW-A2-D was approximately 7.5 SU and the pH measured in IMW-A1-D was 8.1 SU. Both values were below the neutralization target; therefore, Phase 3 was concluded.

During injections for the full-scale Phase 3 testing, pH, temperature, and water levels in the following observation wells were logged for the duration of the testing: MW-53, IMW-A1-D, IMW-A2-D, IMW-A2-S, IMW-B1-S, IMW-B1-D, and IMW-B2-S. MW-29, the vent well, and IMW-C1-S were only monitored for water level and temperature because Phase 1 testing indicated that $CO_2$ injection did not change the groundwater pH in these wells. MW-54 was only monitored for water level and temperature because Phase 1 and 2 testing results indicated that data from this well were not representative of the hydraulic unit where the well was screened. During active injections and the 1-hour rebounds, wellhead pressure was measured in monitoring wells by taking a manual measurement with a digital manometer every 15 minutes, except for IMW-A2-S where a pressure logging transducer was used. Wellhead pressure was not monitored after ending an injection event, except in IMW-A2-S.

A complete groundwater chemistry analysis was performed for all the pilot study wells after Phase 3 injections ceased. The groundwater samples were analyzed for the parameters listed in Table 6. These samples provided data on water chemistry parameters and concentrations of the metals present at the site that may be affected by neutralization of site groundwater. The results from these samples were compared to samples collected in the field prior to $CO_2$ injection. In addition to the groundwater samples collected in the $CO_2$ injection area, weekly samples were collected in nearby MW-28 for four weeks to assess natural variation in dissolved TIC concentrations at the site.

### 3.5.4 Phase 4: rebound monitoring

Upon completion of the Phase 3 injection testing on December 26, 2018, a second period of pH rebound monitoring began. During this rebound monitoring period, pH and temperature were monitored using transducers in the observation wells adjacent to the injection well. Monitoring continued until the pH of the groundwater wells screened in the LAZ stabilized; the groundwater pH in these observation wells was not expected to rebound to initial pH levels as the soil had little buffering capacity and little rebound was observed during Phase 2 testing.

The criteria for ending Phase 4 monitoring was to consider rebound complete once the rate of change of groundwater pH in these wells was less than 0.2 SU over a period of four consecutive weeks. Table 10 summarizes the groundwater monitoring performed during Phase 4. The groundwater pH in IMW-A1-D and IMW-A2-D did not increase in the two-month monitoring period, therefore Phase 4 concluded on February 28, 2019.

At the end of Phase 4, samples were collected from the observation wells and analyzed for the suite of analytes specified in Table 6. The results were compared to analytical results for samples collected during baseline groundwater sampling and samples collected after $CO_2$ injection stopped. These groundwater samples were collected once groundwater pH had stabilized.

# 4.0 Pilot study results

This section presents the results of the pilot study specific to each of the objectives discussed in Section 2.0. Summary data tables for all analytical results specified in Table 6 are presented in Tables 11–13. Raw lab data, transducer data, field notes, groundwater sampling logs, and field forms are available upon request.

## 4.1 Initial $CO_2$ consumption

This section presents results for $CO_2$ consumption rate for the bench-scale and field pilot studies.

### 4.1.1 Bench-scale testing

Groundwater titrations were conducted to assess amount of acid required to neutralize a unit volume of groundwater. Table 14 presents the analytical chemistry results before and after titrating a groundwater sample from the injection well to a pH endpoint of 6.59 SU. The groundwater titration curve for the alkalinity analysis is presented on Figure 10. Figure 11 shows that inflection points occurred during the titration at a pH of approximately 6.5 SU and 4.5 SU. The titration data demonstrate that the buffering capacity of the groundwater is slightly greater than what was modeled in the work plan until a pH value of 6.5 SU, below which the model predicted an inflection point at the first dissociation constant for carbonic acid that was not observed in the groundwater data (note that the model uses carbonic acid as the titrant to simulate injections). The titration data indicate that during $CO_2$ injections the pH will change slowly until a pH of approximately 9 SU after which groundwater should be more responsive per unit volume acid added. Table 11 shows that TDS and dissolved silica concentrations in the injection well groundwater were elevated above site values for other wells presented in Table 1 and 2. Reducing the pH of the groundwater caused the precipitation of dissolved silica, resulting in an increase in TSS. This result indicates that more than 10,000 mg/L TSS may precipitate in the high pH groundwater due to $CO_2$ neutralization. The measured total alkalinity of the injection well groundwater was near 11,000 mg/L $CaCO_2$.

Bench-scale testing was also conducted to determine the buffering capacity of soil in the pilot testing area. The results of Phase 1A and 1B bench-scale testing are presented in Table 15. The results presented in Table 15 show that both soil types have a low buffering capacity; therefore, the minimum acid dose from Stage 1B of 0.5 times the acid demand associated with injection well groundwater was used for Stage 2 testing. The results of Stage 2 testing performed on samples containing soil and deionized water are presented in Table 16 and shown on Figure 11. These results demonstrate that the buffering capacity of both soil types were 5 to 10 ten times less than the total alkalinity of the groundwater in equilibrium with the soil. Table 17 presents the results of Stage 2 testing performed on samples containing soil and groundwater from the injection well. The amount of acid added to the samples was the sum of the quantity required to neutralize the groundwater to a pH of 6.5 SU and an incremental amount associated with 20, 40, 60, and 80 percent of the maximum acid dose for Stage 2 testing. The differences observed between the soil buffering tests conducted with deionized water and those conducted with site groundwater are attributed to excess alkalinity from the groundwater after being neutralized to a pH of approximately 6.5 SU. The large difference in magnitude between the groundwater and soil acid-demand make it difficult to determine if these values are additive. In order to estimate the acid required to neutralize a unit volume of soil and groundwater, it should be assumed that these values are additive as that will result in the most conservative estimate. These findings suggest that both soil types have little buffering capacity and are not expected to rebound after groundwater has been neutralized. These findings are corroborated by the pH rebound data presented in Section 4.5.

The soil and groundwater bench-scale testing found that approximately 95 and 124 milliequivalents acid is required to neutralize one liter of soil and groundwater in the SP and ML-SM units, respectively (assuming a porosity of 0.5, a soil specific gravity of 2.5, and injection well groundwater); the acid demand associated with neutralizing the groundwater in one liter of soil and groundwater is 84 milliequivalents, or 88% and 67% of the total acid demand for the SP and ML-SM units, respectively. This $CO_2$ consumption is theoretical and does not predict the total mass of $CO_2$ that needs to be injected to meet neutralization objectives. In order to determine the total mass of $CO_2$ required to meet neutralization objectives the $CO_2$ utilization efficiency (Section 4.6), groundwater chemistry, and soil properties must also be considered.

### 4.1.2 Pilot-scale testing

Figure 12 presents the change in pH in IMW-A1-D and IMW-A2-D (both 10 feet from the injection well) plotted against the quantity of $CO_2$ injected during all phases of pilot testing. This figure shows the amount of $CO_2$ required to be injected to neutralize high pH groundwater in the subsurface approximately 10 feet from an injection well. The relationship between pH and pounds of $CO_2$ presented in Figure 12 conflicts with the groundwater bench-testing data, which suggested that the rate of neutralization would increase once pH decreased to approximately 9 SU; this is likely due to reaction kinetics and a reduced concentration gradient associated with neutralizing partially neutralized groundwater. As the concentration of carbonic acid in the groundwater increased during active injections, the theoretical partial pressure of $CO_2$ required for dissolution and neutralization increased resulting a decrease in utilization efficiency. Groundwater pH changed the most rapidly during the first five injections of Phase 1 testing, which also conflicts with the bench-scale groundwater testing results. These findings indicate that $CO_2$ utilization efficiency, competing reactions, and subsurface heterogeneity predominantly influence neutralization rates and that the theoretical acid demand and reaction rate observed during the titration cannot be used alone to predict the mass of $CO_2$ required to neutralize a unit volume of groundwater.

### 4.1.3 Conclusions

Bench- and pilot-scale testing yielded the following findings regarding pilot study Objective 1:

- Both soil types have little buffering capacity and are not expected to rebound to pre-injection pH levels after groundwater has been neutralized.
- While a groundwater titration curve can be used to predict the theoretical acid demand of groundwater in the high pH target area, groundwater chemistry, $CO_2$ utilization efficiency, and soil properties will ultimately determine neutralization rates and $CO_2$ demand.

During full-scale neutralization of the high pH target area, the initial groundwater pH and alkalinity data can be used to roughly estimate $CO_2$ demand; however, a conservative utilization efficiency must be applied as subsurface conditions are expected to vary.

## 4.2 $CO_2$ injection rates and injection pressures

This section presents the results for pilot study Objective 2 relating $CO_2$ injection pressure to $CO_2$ flow rates.

### 4.2.1 Pilot-scale testing

Phase 1 testing evaluated a range of injection pressures and the corresponding $CO_2$ flow rates. Throughout each injection event during Phase 1, the pressure at the injection well would steadily decrease. To maintain a constant injection pressure, the pressure regulating valve was adjusted manually several times throughout an injection event. These adjustments caused the $CO_2$ flow rate to increase steadily for the duration of each injection event. The flow rates presented in Table 7 represent the average flow rate over the entire course of each injection event. Figure 13 presents a plot of the relationship between injection pressure and average $CO_2$ flow rate. The figure shows that the relationship between injection pressure and average $CO_2$ flow rate is approximately linear. The average $CO_2$ flow rate increased as injection pressure increased. This information alone is not sufficient to determine an optimal operating point for $CO_2$ to neutralize the high pH target areas.

Phase 3 testing evaluated a constant flow rate of 19.8 SCFM and injections were cycled as described in Section 3.5.3. Figure 14 shows the pressure required to maintain constant flow during Phase 3 injection events 1, 5, and 21 to track how injection pressure changed during Phase 3; these three events were selected to show the changes across the Phase 3 injection program. Figure 14 shows the initial pressure at the injection well for the first injection of each event ranged from 29 psi (injection event 1) to 23 psi (injection event 21) and steadily decreased during each of the injection cycle. During the first rebound period, pressure at the injection well dropped to approximately 14 psi and then continued to steadily decrease. During the second and third injection cycles, the injection pressure required to maintain constant flow continued to steadily decrease from the pressure during the first cycle.

Figure 15 presents the initial pressure and final pressure recorded during Phase 3 injection events. The figure shows that over the course of several consecutive days of injection events the initial injection pressure decreased. After an extended period of rebound the initial injection pressure required to maintain a flow of 19.8 SCFM generally increased. The final injection pressure generally decreased after multiple consecutive days of injection events. This is likely due to residual gas present in soil pore spaces displacing fluid after an injection; after multiple consecutive days of injection events , the amount of residual subsurface $CO_2$ gas increased, which decreased the hydrostatic pressure that must be overcome to maintain a constant flow of 19.8 SCFM.

The trend of decreasing injection pressure required to maintain constant $CO_2$ flow over the course of multiple injections also indicates that precipitation of amorphous silica or other solids during neutralization does not sufficiently alter effective porosity to necessitate increasing injection pressure.

### 4.2.2 Conclusions

Pilot-scale testing yielded the following findings regarding pilot study Objective 2:

- The relationship between injection pressure and the average $CO_2$ gas flow rate is approximately linear.
- An optimal injection pressure and rate for $CO_2$ to neutralize high pH target areas could not be established solely using the relationship between injection rate and injection pressure. Other parameters such as groundwater mounding characteristics, $CO_2$ utilization efficiency, and the radius of influence were required to determine optimal operating conditions.
- Precipitation of solids during groundwater neutralization did not alter aquifer characteristics enough to require increasing injection pressure.

The relationship between injection pressure and flow rate and the effects of precipitation of solids during groundwater neutralization depend on aquifer and well characteristics and would need to be monitored during future $CO_2$ injections at the site. However, data from pilot-scale testing suggests that precipitation of solids will not inhibit the injection of $CO_2$ to neutralize groundwater.

## 4.3 Radius of influence

Pilot testing was performed to estimate the ROI of an injection well, which could be used to determine the number of wells needed to neutralize areas impacted by high pH (Objective 3). ROI is determined through monitoring injection wellhead pressures, pH in observation wells, and changes in groundwater chemistry such as through changes in TIC.

### 4.3.1 Natural variation in dissolved total inorganic carbon

Through pilot testing observations, it was determined that dissolved TIC may be an effective method of assessing the ROI from injection of gaseous $CO_2$. Given that there may variability in concentrations of TIC that may be dependent on several factors, weekly samples were collected in nearby monitoring well MW-28 for four weeks during Phase 3 and analyzed for dissolved TIC to assess natural variation in dissolved TIC at the site. The natural variation of dissolved TIC in MW-28 was assumed to represent natural variation in the pilot testing area because:

- MW-28 is located inside the barrier wall and within the area of elevated pH in the southwest corner of the site;

- MW-28 is greater than 100 feet from the injection well and would not be affected by $CO_2$ injection; and
- Groundwater in MW-28 has a similar chemistry to groundwater in the pilot testing area.

The groundwater pH and dissolved TIC concentration for these samples is presented in Table 18. The coefficient of variation for dissolved TIC in MW-28 was 22.5%. During pilot testing, any change in dissolved TIC greater than 22.5% was considered significant, and any change less than 22.5% was considered to be not significant and attributable to natural variation of groundwater chemistry at the site. The 2018 technical memorandum discussing pilot testing results (Wood 2018) used a value of 10 mg/L or a percentage change in dissolved TIC of 4.7% as indicators of a substantial change; these values were preliminary screening levels used to make real time field decisions. After reviewing the technical memorandums, the EPA and Wood agreed that collection of site-specific data to determine natural variation in dissolved TIC would better define a substantial change. The fourth sample collected contributed most to the coefficient of variation. The coefficient of variation excluding the fourth sample would have been 0.9%, however review of the laboratory report associated with this sample identified no problems and concluded that the data were acceptable and met the project's data quality objectives outlined in the QAPP. The site-specific data collected indicated greater natural variation in dissolved TIC than was initially anticipated; therefore, pilot testing results interpretation differ slightly from what was presented in the technical memorandums.

### 4.3.2 Pilot-scale testing

The ROI during injection events for each phase was estimated using changes in pH and dissolved TIC in groundwater sampled before and after the injection event. Well headspace pressure, water levels, and water temperature were also used to support evaluation of the ROI. The water level data show that for Phase 1 injection events 2 through 5, all monitoring wells had water level changes greater than 0.10 foot. This suggests an ROI of at least 32 feet, which is the horizontal distance from the injection well to MW-29. However, results showed changes in groundwater chemistry, pH, and temperature were not observed in all the monitoring wells after each injection event. This finding suggests that changes in pH, temperature, and dissolved TIC concentrations are better indicators of the ROI than changes in water level. Changes in water levels this distance away may be attributed to displacement of groundwater from surface pore spaces rather than areas influenced by dissolution of $CO_2$.

Figure 4 presents a plan view of the injection area and the locations of two cross sections that were used to evaluate the ROI of each injection. Cross section C-C' shows how groundwater was affected by $CO_2$ injections along a line orthogonal to the barrier wall, and cross section D-D' shows these effects along a line parallel to the barrier wall. The cross sections in Figure 16 through 20 show changes in dissolved TIC concentrations, changes in pH, and the approximate shape of the groundwater mound formed in the LAZ along these cross sections following Phase 1 injection events 1 through 5. The figures show that dissolved TIC concentrations either increased greater than the coefficient of variation or were not significantly impacted following each injection event. An approximate ROI is shown on the figures and was based on pH and dissolved TIC data. These changes are also presented in Table 19, which also presents changes in temperature.

Below is a discussion of the ROI for each injection event:

- Injection Event 1: Injection event 1 maintained a constant pressure of 18 psi and the average flow was 4.3 SCFM. Figure 16 summarizes the effects of the Injection Event 1. The first injection event had a negligible effect on dissolved TIC concentrations and pH in monitoring wells screened in the LAZ and UAZ, except for MW-54, which experienced an increase in dissolved TIC and is within 10 feet of the injection well. An increase in pH was observed in MW-53, which is likely due to the displacement of high pH groundwater. The practical ROI for Injection Event 1 was less than 10 feet and limited to the LAZ.

- Injection Event 2: Injection event 2 maintained a constant pressure of 20 psi and the average flow was 12.1 SCFM. Figure 17 summarizes the effects of the Injection Event 2. Changes in dissolved TIC concentrations were negligible in all monitoring wells in both aquifer zones except for increases in MW-53 and MW-54, which are both within 10 feet of the injection well. The groundwater pH in MW-53, MW-54, IMW-A1-D, and IMW-A2-S all decreased by more than 0.1 SU; all these wells are 10 feet or less away from the injection well. An increase in pH was observed in IMW-B1-S, which is likely due to the displacement of high pH groundwater due to the groundwater mounding in the lower aquifer. The practical ROI for Injection Event 2 was less than 10 feet and limited to the LAZ.
- Injection Event 3: Injection event 3 maintained a constant pressure of 23 psi and the average flow was 15.5 SCFM. Figure 18 summarizes the effects of the Injection Event 3. Changes in dissolved TIC concentrations were negligible in all monitoring wells in both aquifer zones except for MW-53 and MW-54, which are both within 10 feet of the injection well. The pH in IMW-A1-D decreased by approximately 0.3 SU. No pH or TIC concentration changes were observed in IMW-A2-D, suggesting that the practical ROI was greater in the direction orthogonal to the barrier wall. The groundwater pH in MW-53, MW-54, IMW-A1-D, and IMW-A2-S all decreased by more than 0.1 SU; all of these wells are 10 feet or less away from the injection well. The practical ROI for Injection Event 3 was less than 10 feet and limited to the LAZ.
- Injection Event 4: Injection event 4 maintained a constant pressure of 26 psi and the average flow was 19.8 SCFM. Figure 19 summarizes the effects of Injection Event 4. Dissolved TIC concentrations increased in MW-54, IMW-A1-D, and IMW-A2-D. All these wells are within 10 feet of the injection well. The groundwater pH in MW-53, MW-54, IMW-A1-D, IMW-A2-D, and IMW-A2-S all decreased by more than 0.1 SU; all these wells are 10 feet or less away from the injection well. The pH in IMW-A1-D and IMW-A2-D increased slightly in the 24-hour period after the injection event, but decreased rapidly after being purged for groundwater sampling. This observation suggests that the pH values in groundwater in the LAZ formation near IMW-A1-D and IMW-A2-D were likely lower than the pH of the groundwater within the well screen interval. The ROI for Injection Event 4 was at least 10 feet and primarily in the LAZ.
- Injection Event 5: Injection event 5 maintained a constant pressure of 28 psi and the average flow was 25.7 SCFM. Figure 20 summarizes the effects of Injection Event 5. Dissolved TIC concentrations increased in MW-54, IMW-A1-D, IMW-A2-S, and IMW-A2-D. All these wells are within 10 feet of the injection well. The groundwater pH in MW-53, MW-54, IMW-A1-D, IMW-A2-D, and IMW-A2-S decreased by more than 0.1 SU. The groundwater pH decreased in IMW-A1-D and IMW-A2-D by 0.6 and 1.1 SU, respectively. The ROI for Injection Event 5 was at least 10 feet and in both aquifer zones.

During injection events 2 through 5, the temperature increased by 0.1 to 0.6 °C in all the wells screened in the LAZ except IMW-B1-D. These temperature increases can be attributed to the heat released by the neutralization of high pH groundwater and the dissolution of $CO_2$. The temperature data suggest an ROI in the LAZ of 10 feet or more for injection events 2 through 5.

Table 20 shows the minimum and maximum wellhead pressure observed during each injection event and the 30-minute period following each injection. Wellhead pressure generally increased during active injections and decreased to levels below atmospheric pressure after the injection event ended. During injections, wellhead pressure was generally greatest in the deep wells; however, a consistent trend across all five injection events was not observed. Wellhead pressure generally did not correlate with changes in pH or TIC, and therefore was not considered a good indicator of practical ROI.

Table 19 shows the change in groundwater pH and dissolved TIC concentration before and after Phase 3 testing. Figure 21 presents cross sections summarizing the effects of Phase 3 injections; the approximate shape of the groundwater mound was not included because it varied by injection and is discussed in further detail in Section 4.4. The dissolved TIC concentration increased in MW-54, IMW-A1-D, IMW-A2-D, IMW-A2-S, IMW-B2-S, and IMW-B1-D. The groundwater pH decreased by at least 0.25 SU in MW-53, MW-54, IMW-A1-D, MW-29, IMW-A2-D, IMW-A2-S, IMW-B1-D and IMW-B1-S. These data suggest that the ROI for the injection well was between 10 and 20 feet, which is consistent with Phase 1 testing. The small change in groundwater pH observed in IMW-B1-D suggests that while groundwater 20 feet from an injection well is influenced by the injection of $CO_2$, it is not close enough to be efficiently neutralized.

### 4.3.3 Conclusions

The Phase 1 data show that the ROI expanded as injection pressure increased. The greatest changes in pH and dissolved TIC concentrations were observed at injection pressures of 26 psig and above. At an injection pressure of 26 and 28 psi, the ROI of the injection well is between 10 and 20 feet. Both injection pressures were considered optimal for Phase 3 testing.

Pilot testing yielded the following conclusions regarding pilot study Objective 3:

- The ROI increased as injection pressure increased.
- At an injection pressure above 26 psi, the ROI for the injection well was between 10 to 20 feet.
- During Phase 3 injections, groundwater 20 feet from the injection well experienced an increase in dissolved TIC; however, not enough $CO_2$ was received to neutralize groundwater to the target of 8.5 SU.

The ROI of injection wells of a full-scale system is anticipated to vary with well location due to soil heterogeneity. Monitoring wells should be used to assess the actual ROI of installed injection wells to assess if the actual ROI of the full-scale systems differ from what was determined in the pilot study. Additionally, if the actual ROIs in a full-scale system differ from that determined in the pilot study, injection wells may need to be added to fully address the areas impacted by high pH.

## 4.4 Groundwater mounding

Phase 1 and Phase 3 of the pilot test assessed groundwater mounding and collapse during $CO_2$ injection (pilot study Objective 4). The objective of this testing was to assess groundwater mounding and collapse to support optimization of a full scale system including operation and maintenance requirements and potential for surface expression and/or mobilization of groundwater to surface water of mounded water (for example in the Shoreline Area where an impermeable cover is not present).

### 4.4.1 Pilot-scale testing: Phase 1

Figures 22 through 26 shows contours for the maximum change in water level based on the maximum extent of groundwater mounding during $CO_2$ injection in the LAZ compared to a 30 minute average water level measured prior to beginning an injection cycle.

#### 4.4.1.1 Lower aquifer zone

The groundwater mound formed by the injection of $CO_2$ increased in area and height as injection pressure increased. Figure 27 presents the water level trends observed in IMW-A2-D for each injection event during Phase 1 and during the 36-hour period following each injection event. The shape of the water level trends are similar for all the wells screened in the LAZ, although the magnitude of water level increase varied. The water level increased continuously throughout the injection event, which suggests that injection pressure was not high enough for gas channels to reach the vadose zone and stabilize water levels.

Groundwater mounding was greatest in monitoring wells close to the barrier wall, suggesting that the injection of $CO_2$ caused groundwater to push up against the wall and accumulate. Groundwater mounding was greater in the direction orthogonal to the barrier wall (northwest) than it was in the direction parallel to the barrier wall (northeast); this shape is potentially a result of the barrier wall.

The characteristics of groundwater mounding in the LAZ explain some of the observed changes in pH in several of the shallower wells. The groundwater pH in IMW-B1-S increased during each injection, whereas the pH in IMW-A2-S and IMW-B2-S generally declined. Figures 22 through 26 show that groundwater mounding was greater under IMW-B1-S than it was under IMW-A2-S and IMW-B2-S. The observed pH increase during injection events were likely the result of groundwater from the lower aquifer being displaced upward into the UAZ.

After stopping the flow of $CO_2$, groundwater levels generally collapsed to below pre-injection values. The mound collapse was greatest in MW-54; this was likely because MW-54 is the closest monitoring well to the barrier wall and the injection well. Groundwater mounding was greatest near the barrier wall; therefore, a greater volume of gas-filled pores was present in that area. Once $CO_2$ flow stopped, these pores re-saturated with groundwater causing a greater collapse than what was observed in other areas in the pilot study. The time required for groundwater levels to rebound to pre-injection levels increased with injection pressure; 36 hours were required for water levels to rebound after Injection 5. Groundwater levels also collapsed to a deeper depth as injection pressure increased.

#### 4.4.1.2 Upper aquifer zone

The changes in water level observed in the UAZ during injection events were smaller than the changes observed in the LAZ. Water level increases were less than 1 foot in the wells screened in the UAZ during every injection event. Figures 22 through 26 present the maximum change in water level observed during each injection; contours were not drawn for these figures as the difference in water levels among UAZ wells was generally less than 0.1 foot.

During injections, water levels in the UAZ increased most rapidly during the first hour of the event. Figure 28 presents the water level trends in IMW-A2-S for each injection event and the 12-hour period following each injection event. This trend is similar for all the UAZ wells. As the injection pressure increased, the time required to reach the maximum water level decreased. Higher injection pressures caused the groundwater mound to collapse to a lower elevation once the injection ended. The water level in the UAZ generally rebounded to pre-injection levels faster than water levels in the UAZ, occurring within 6 hours of ending the injection.

#### 4.4.1.3 Optimal parameters

Phase 3 testing parameters were determined by analyzing the results from Phase 1 and optimizing parameters for future $CO_2$ injections for areas such as in the Shoreline Area. Phase 3 injections included testing pulse injections to promote mixing and $CO_2$ distribution in the injection zone. From the ROI discussion above, an injection pressure of 26 psig was selected as this resulted in a similar ROI as 28 psig. Note that the mound observed in injection event 5 with an injection pressure of 28 psig was 8.45 feet above the average groundwater level measured prior to injecting $CO_2$ compared to 7.33 feet for injection event 4 with an injection pressure of 26 psig. Limiting mounding while maximizing ROI was considered when establishing a target injection pressure to assess in Phase 3 pilot testing given proximity to Slip 6 when considering injections in the Shoreline Area and potential for upward displacement of high pH groundwater from the LAZ.

The duration of active injection time was determined using the water level data for IMW-A2-S presented on Figure 28 for injection event 4. An injection time of 2 hours was selected because that was the time required to reach the maximum water level at an injection pressure of 26 psig. A rebound time of 1 hour was selected because that was the time required for water levels to begin to rebound at an injection pressure of 26 psig. This timing allowed for three cycles per day.

### 4.4.2 Pilot-scale testing: Phase 3

Figure 29 shows the approximate shape of the maximum extent of groundwater mounding during $CO_2$ Injection Event 9 in the LAZ; the figure also shows the maximum increase in water level recorded in the UAZ during each injection event. Phase 3 Injection Event 9 was selected because it was generally representative of observations during all other events.

#### 4.4.2.1 Lower aquifer zone

Figure 30 presents the water level trends observed in IMW-A2-D during injection events 1, 4, 9, 14, 18, and 21 as well as the groundwater rebound. IMW-A2-D is shown as it was one of the wells where the largest impacts resulting from $CO_2$ injections were observed. The general shape of the water level trends is similar for all the wells screened in the LAZ. The water level increased rapidly in the first half hour and then continued to slowly increase throughout each injection cycle to a value of 3 to 5 feet above pre-injection values; during the one hour rebound period water levels dropped to slightly below pre-injection levels after approximately 1 hour. The maximum water level during all three injection cycles was similar for all three injection cycles in a given injection event. After the final injection cycle, groundwater collapsed to 1 to 2 two feet below pre injection levels and then either rebounded within 36 hours, or approximately 16 hours at the start of the following injection event. Figure 30 also shows that groundwater mounding during the first injection event occurred much slower and to a lesser extent than during subsequent injection events. This observation suggests that multiple injection cycles resulted in additional preferential flow paths resulting in$CO_2$ reaching the groundwater surface more quickly during later injection events.

The shape and height of the groundwater mound formed by the injection of $CO_2$ were different for Phase 3 than observed during Phase 1 testing (Figure 29). While groundwater mounding was greatest in monitoring wells close to the barrier wall, similar to what was observed during Phase 1, mounding was greater in the direction parallel to the barrier wall (northwest) than it was in the direction orthogonal to the barrier wall (northeast) which was not observed during Phase 1. Groundwater mounding was greater in IMW-A2-D (parallel to the wall) than IMW-A1-D (orthogonal to the wall) by 1 foot for all Phase 3 injections; this is the opposite of what was observed during Phase 1 testing. This change potentially arises because of channelization in the subsurface during $CO_2$ injection creating preferential flow paths. This finding suggests that soil heterogeneity and development of preferential flow paths influence the shape of the groundwater mound to a greater extent than the barrier wall. It follows that while mounding was greatest in MW-54, it is uncertain whether this is due to the presence of the barrier wall or differences in soil properties.

#### 4.4.2.2 Upper aquifer zone

The changes in water level observed in the UAZ during injection events were smaller than the changes observed in the LAZ; this is consistent with what was observed during Phase 1. Water level increases were less than 1.5 feet in the wells screened in the UAZ during every injection event. Figure 29 presents the maximum change in water level observed during Injection Event 9.

Figure 31 presents the water level trends in IMW-A2-S during and the 12-hour period following injection events 1, 4, 9, 14, 18, and 21. During injections, water levels in the UAZ initially decreased in the first few minutes of $CO_2$ injection, and then increased rapidly during the next half hour of the cycle; water levels would peak approximately one half hour into the injection cycle and then begin to slowly fall. During the 1 hour rebound period, water levels dropped to slightly below pre-injection levels which was consistent with Phase 1 trends. Groundwater mounding characteristics during the subsequent two injection cycles were generally similar to characteristics during the first cycle. After the final injection cycle, groundwater generally rebounded within 2 to 3 hours. These conditions allow for six to seven rapid changes in groundwater elevation during the injection event, creating groundwater mixing conditions.

Figure 32 shows the headspace recorded in IMW-A2-S during and after the 12-hour period following injection events 4, 9, 14, 18, and 21. Wellhead pressure increased the most rapidly during the first 30 minutes, and then slowly decreased. Once the injection of $CO_2$ stopped, wellhead pressure dropped below pre-injection values, creating a slight vacuum against atmospheric pressure. Wellhead pressure rebounded back to atmospheric pressure after 2 to 8 hours. The water level and wellhead pressure trends were relatively constant over the course of Phase 3 injections.

Wellhead pressure was greatest in MW-53, in which values greater than 7 psig were recorded. The wellhead gas contained hydrogen sulfide; the maximum concentration recorded exceeded 50 mg/L. Note that the Occupational Safety and Health Administration's Permissible Exposure Limit for hydrogen sulfide is 20 mg/L; the 10-minute maximum exposure concentration is 50 mg/L. Hydrogen sulfide generation is expected as groundwater neutralization allows for natural biodegradation of site constituents. Hydrogen sulfide gas has been observed in MW-52 in the southwest corner of the site, which suggests that it is a natural byproduct of biodegradation of site COCs in neutral groundwater. While a hazardous aboveground atmosphere was not observed during pilot-scale testing, full-scale injections in the high pH target area will be conducted in an unpaved area and closer to the waterway, therefore air quality monitoring should be included to monitor for potentially adverse impacts on human health and the environment.

### 4.4.3 Conclusions

Pilot-scale testing yielded the following results regarding Objective 4:

- Injection cycles consisting of 2 hours of active injection and 1 hour of rebound helped to promote groundwater mixing while minimizing the upward displacement of high pH groundwater.
- Mounding was greater between the barrier wall and the injection well; however, it is uncertain whether this difference is due to the barrier wall or soil heterogeneity.
- Injection of $CO_2$ caused the upward displacement of high pH groundwater from the LAZ to the UAZ.
- The generation of hydrogen sulfide occurred and is expected during full-scale injections; therefore, air quality monitoring should be included to monitor for potentially adverse impacts on human health and the environment.

Conditions in future injection wells are expected to vary with well location due to soil heterogeneity; therefore, groundwater mounding and collapse will need to be monitored during active injections to prevent the displacement of high pH groundwater upward into the UAZ or into the Duwamish Waterway. In addition, the impacts of tidal water level fluctuations were not assessed during pilot-scale testing and need to be considered during full-scale injections.

## 4.5 Assessment of pH neutralization and rebound rates

This section presents results related to pilot study Objective 5 regarding pH neutralization and rebound rates.

### 4.5.1 Pilot-scale testing

During Phase 1, a total of 3,658 pounds of $CO_2$ were injected resulting in a reduction in groundwater pH of approximately 2 SU in IMW-A1-D and IMW-A2-D. An average of 1,740 pounds of $CO_2$ was required to reduce the groundwater pH within 10 feet of the injection well by one SU. Neutralization in IMW-B2-D did not occur; therefore, the extent of groundwater neutralization during Phase 1 was between 10 and 20 feet. The pH in the UAZ remained relatively constant, except in MW-53 and IMW-A2-S, where pH decreased steadily after each injection event. Although groundwater pH in the LAZ decreased during injection events 2 through 5, not enough $CO_2$ was injected into groundwater to meet neutralization goals.

Figures 33–35 show pH and temperature trends for Phase 1 injections. Note that several increases in pH and temperature that occurred during or immediately after monitoring events shown on the figures appear to be correlated with purging each well prior to sample collection. These changes are most pronounced in the wells screened in the LAZ, and in MW-54 likely due to the low hydraulic conductivity associated with the silty sand layer. The purging of the well prior to sampling likely caused water from the LAZ to be mixed into the well screen interval. This suggests that groundwater in the well screen may vary from aquifer conditions adjacent to the well. The changes in MW-54 likely occurred because the well is screened in the silt aquitard layer and part of the well sand pack extends into the overlying poorly graded sand by approximately 2 feet. The large changes in pH and temperature are likely the result of drawing in water from the silty sand layer above the well screen during sampling. After sampling, the pH in the well generally increased slowly; this is likely a result of back diffusion of high pH groundwater from the silt aquitard.

The Phase 2 pH and temperature trends are presented in Figure 36–38. In the LAZ, pH increased by less than 0.5 SU over eight weeks in IMW-A1-D, IMW-A2-D, and IMW-B1-D after completing Phase 1 groundwater sampling. This result suggests that any rebound capacity of the soil was quickly consumed after neutralization, which is consistent with soil buffering capacity results. The pH in the injection well increased by approximately 0.4 SU during the first week of monitoring. The rate of pH increase slowed after the first week, and the pH changed by less than 0.2 SU during the remainder of Phase 2. In the UAZ the average pH in IMW-A2-S and IMW-B1-S decreased during the 5-day period after the final injection event. The average pH stopped decreasing after groundwater sampling occurred, suggesting that the pH outside of the well screen had a lower pH. While the groundwater pH in IMW-A2-S and IMW-B1-S appears to be tidally influenced, the average pH value did not rebound to pre-injection values. Two large spikes in pH were observed in IMW-B1-S on June 12 and June 24, 2018. No abnormalities in water level or temperature were observed during these periods. The average pH changed less than 0.2 SU for the remainder of Phase 2, suggesting that the spikes were not significant changes to the upper aquifer zone groundwater. The pH in MW-53 increased steadily at a slow rate, changing less than 0.5 SU during Phase 2 (8 weeks).

During Phase 3 testing, approximately 21 injection events, 122 hours of injecting $CO_2$, and 61 injection cycles were required to meet neutralization goals. A total of 16,457 pounds of $CO_2$ was injected during Phase 3. Figures 39 and 40 show pH and temperature trends for Phase 3 injections. IMW-A1-D and IMW-A2-D both met neutralization goals. The average groundwater pH reduction for IMW-A1-D in a single injection event was approximately 0.1 SU. This corresponds to an average of 8,250 pounds of $CO_2$ to reduce groundwater pH by one SU in monitoring wells within 10 feet of the injection well. Neutralization in IMW-B2-D did not occur; therefore, ROI for groundwater neutralization during Phase 3 was between

10 and 20 feet. The rate of neutralization during Phase 3 was less than that of Phase 1, which suggests that the rate of neutralization slowed over the course of the pilot study. The reduction in rate of neutralization is potentially due to a decrease in $CO_2$ utilization efficiency possibly caused by either (1) a lower concentration gradient, which decreased the rate of $CO_2$ transport; or (2) development of preferential flow paths (as discussed further in Section 4.6).

In the UAZ, pH during Phase 3 remained largely unchanged, but increased temporarily during injection events due to the upward displacement of high pH groundwater in IMW-B1-S, IMW-A2-S, and MW-53. In IMW-A2-S, the magnitude of the pH increase decreased during Phase 3, which is likely because the pH of the groundwater in the LAZ below IMW-A2-S decreased with each injection event. The magnitude of the pH increases during active injections in IMW-B1-S groundwater did not decrease by as much during Phase 3 because groundwater 20 feet away from the injection well in the LAZ was not neutralized.

The Phase 4 pH and temperature trends are presented in Figures 41 and 42. While groundwater pH in the LAZ spiked after wells were purged for groundwater sampling, the pH in IMW-A1-D, IMW-A2-D, IMW-B1-D, and the injection well increased by less than 0.2 SU during the two months of monitoring during Phase 4. The small rebound during Phase 2 and Phase 3 injections likely consumed all the soil's buffering capacity. The temperature in the UAZ wells did not increase or decrease by more than 0.5°C during Phase 4. In the UAZ, the average pH in all wells changed by less than 0.3 SU during Phase 4 monitoring. The average temperature in all UAZ wells decreased by less than 0.5°C during Phase 4 monitoring; however, the temperature in IMW-A2-S, MW-53, IMW-B1-S, and IMW-B2-S fluctuated with a tidal patten. The transducer in IMW-B1-S was replaced with a new, recently calibrated transducer on February 18, 2019, to confirm the pH fluctuations; pH fluctuation continued after the new transducer was installed, after which the transducer was removed on February 22, 2019. During Phase 4, the pH in UAZ wells did not rebound to pre-injection values.

### 4.5.2 Conclusions

Pilot-scale testing yielded the following results regarding Objective 5:

- The soil has a low buffering capacity, therefore the initial groundwater neutralization at the site is likely permanent with little to no rebound.
- Approximately 20,115 pounds of $CO_2$ over 26 injection events was required to neutralize all groundwater within a 10- to 20-foot radius of an injection well (throughout Phases 1 and 3).
- An average of 5,100 pounds of $CO_2$ was required to reduce the groundwater pH by one standard pH unit within 10 feet of the injection well (throughout Phases 1 and 3).
- The rate of groundwater neutralization slowed during pilot-scale testing.

Conditions in future injection wells are expected to vary with well location due to soil heterogeneity; therefore, groundwater monitoring is necessary to assess actual neutralization rates and to control operations. In addition, while soil in the pilot study area had a low buffering capacity, the characteristics of soil outside of the barrier wall may vary; therefore, rebound monitoring must be included during scaled-up injections.

## 4.6 $CO_2$ utilization efficiency and consumption

A $CO_2$ utilization efficiency and consumption rate is necessary to determine the mass of $CO_2$ required to neutralize soil and groundwater in the high pH target area (Objective 6).

### 4.6.1 $CO_2$ utilization groundwater zones

For calculations, the aquifer was divided vertically into three different zones: an upper zone from 16 to 25 feet bgs (corresponding to the shallowest observation well screens), a middle zone from 25 to 40 feet bgs (corresponding to mid-depth observation well screens), and a lower zone from 40 to 50 feet bgs (corresponding to the deepest observation well screens). The aquifer was also divided radially outward from the injection well based on interpolating between observation points. These zones of representative groundwater are shown schematically on Figure 43. Groundwater conditions were assumed to be homogeneous within each of these zones for purposes of calculating $CO_2$ utilization efficiency. For example, all the groundwater between 16 and 25 feet bgs and within 15 feet of the injection well was assumed to have the same dissolved TIC concentrations as the vent well.

### 4.6.2 Pilot-scale testing

The $CO_2$ utilization efficiency during Phase 1 and Phase 3 was calculated using two methods:

- Method one involved measuring changes in dissolved TIC concentrations in groundwater and comparing these changes against the mass of $CO_2$ injected.
- Method two involved comparing the theoretical acid demand to neutralize groundwater and soil within the radius of influence against the total mass of $CO_2$ injected.

For method one, the $CO_2$ utilization efficiency was calculated as the percentage of $CO_2$ delivered to the aquifer and available for neutralization of the groundwater (i.e., the total quantity of $CO_2$ dissolved into groundwater as measured by TIC analyses), divided by the total mass of $CO_2$ injected. Sample calculations for $CO_2$ utilization efficiency are presented in Calculation 1. The total amount of $CO_2$ injected is presented in Tables 7 and 8. The total $CO_2$ delivered to each monitoring well was calculated using the change in dissolved TIC concentrations before and after each injection event. It was assumed that groundwater TIC concentrations were the same as the concentrations in samples collected in the monitoring well within the groundwater's zone as shown on Figure 43.

Table 19 presents changes in TIC concentrations and pH measured before and after an injection event, as well as the calculated quantity of $CO_2$ delivered to the well's representative groundwater. Monitoring wells that had negative changes in TIC concentrations or changes less than 22.5 percent were not included in the calculation of the total mass of $CO_2$ delivered to the aquifer. The total mass of $CO_2$ delivered to the aquifer and the total mass of $CO_2$ injected were then used to determine the overall injection event utilization efficiency.

Figure 44 presents the $CO_2$ utilization efficiency for each Phase 1 injection pressure and for Phase 3. The utilization efficiency was greatest during the Injection Event 5 of Phase 1, at 30 percent. The Phase 3 utilization efficiency was lower than observed during Phase 1 testing. This decrease is potentially associated with either (1) the lack of precision in the method for calculating utilization efficiency or (2) channelization and the development of preferential gas flow paths may have reduced $CO_2$ delivery to groundwater near the injection wells. A decrease in $CO_2$ utilization efficiency may also occur because as groundwater was neutralized the concentration gradient of carbonic acid decreased, reducing the rate of $CO_2$ mass flux.

The utilization efficiency for both Phase 1 and 3 testing was also calculated using method 2, where the theoretical acid demand of the pilot testing area was determined assuming a soil porosity of 0.5, a depth of 10 feet (corresponding to 40 to 50 feet bgs and the high pH target area), and the injection well's acid demand required to reduce groundwater pH to the post Phase 4 value as measured during groundwater bench testing. The total mass of $CO_2$ injected during pilot testing was 20,115 pounds. The calculation is presented in Calculation 2. The $CO_2$ utilization efficiency using this method was 5.4%.This calculation also assumes the groundwater in the pilot testing area is similar in quality to the injection well groundwater. The $CO_2$ utilization efficiency calculated using method two is similar in magnitude to the efficiency calculated using method one. It follows that the method two $CO_2$ utilization efficiency provides a conservative estimate that can be used for estimating the $CO_2$ required to neutralize groundwater in the high pH target area.

### 4.6.3 Conclusions

Pilot-scale testing produced the following results regarding Objective 6:

- A conservative $CO_2$ utilization efficiency of 5.4% should be assumed for the design of neutralizing the high pH target area.
- $CO_2$ utilization efficiency decreased over multiple injections.

While the $CO_2$ utilization efficiency is expected to vary given differing soil properties, a conservative value can be used for cost estimates.

## 4.7 Changes in aquifer characteristics

Prior to pilot testing, it was anticipated that as groundwater is neutralized, amorphous silica (and possibly other silicates) would precipitate onto the subsurface aquifer soil matrix. Slug testing was performed to assess changes in aquifer characteristics, specifically whether precipitation of solids impacted effective soil porosity (Objective 7).

### 4.7.1 Slug testing

Table 20 presents the slug testing results before and after pilot testing. Because the well screen intervals for all wells tested are fully submerged and below the water table in an unconfined aquifer, slug-in and slug-out results should be directly comparable. The changes in hydraulic conductivities in wells tested before and after pilot testing are as follows:

- Injection well—Slug-in and slug-out tests yielded an increase and decrease in hydraulic conductivity, respectively. This change in hydraulic conductivity is minor and unlikely to have impacted injections and $CO_2$ delivery.
- IMW-A1-D—Slug-in and slug-out tests yielded an increase and decrease in hydraulic conductivity, respectively. This change in hydraulic conductivity is minor and unlikely to have impacted injections and $CO_2$ delivery.
- MW-53—Both slug-in and slug-out tests yielded a small (5 to 60%) decrease in hydraulic conductivity. This change in hydraulic conductivity is minor and unlikely to have impacted injections and $CO_2$ delivery.
- MW-54—Both slug-in and slug-out tests yielded a small (36 to 49%) decrease in hydraulic conductivity. Due to how this well was screened, it is uncertain whether the changes are associated with the silt aquitard or the LAZ. The change in hydraulic conductivity is minor and unlikely to have impacted injections and $CO_2$ delivery.

These results are consistent with injection pressure trends presented in Figures 14 and 15, which suggest that the precipitation of amorphous silica and other solids did not affect aquifer characteristics.

### 4.7.2 Conclusions

Pilot-scale testing produced the following results regarding Objective 7:

- Precipitation of amorphous silica and other solids did not affect aquifer characteristics.

Precipitation onto subsurface aquifer soil matrix and pore space fouling can be better assessed during full-scale neutralization of high pH target area by monitoring injection pressure for sudden increases during injection cycles.

## 4.8 Changes in groundwater and soil chemistry

Groundwater samples were collected before and after the injection of $CO_2$ to assess water chemistry changes caused by $CO_2$ injections (Objective 8).

### 4.8.1 Analytical results

Analytical results of groundwater sampling are presented in Tables 11—13. The groundwater analyses could not be assessed using equilibrium modeling due to an incomplete charge balance; therefore, changes in water chemistry for site-specific COCs were compared against PRGs. Figures 45 and 46 show the changes in site metals concentrations throughout the pilot study, compared against PRGs as presented in the CMS workplan (AMEC 2014) or other limits that may affect site remediation.

Injection of $CO_2$ generally led to decreased concentrations for site COCs. Copper is a key site COC. The pre-injection copper concentrations ranged from 2.9 to 286 micrograms per liter (µg/L). The upper end of this range is also greater than what has historically been measured in wells outside of the barrier wall. In MW-53, the copper concentrations decreased during pilot-scale testing from 286 µg/L to 6.61 µg/L, which is below the PRG. In IMW-A1-D and the injection well, the copper concentration decreased by an order of magnitude, but remained slightly above the PRG. The copper concentration in MW-54 increased from below the PRG to slightly above it; however, as previously discussed, the representativeness of groundwater from MW-54 is unclear. These results indicate that the copper concentration is expected to decrease as groundwater is neutralized; this trend is consistent with previous site investigations that have found lower copper concentrations in areas of more neutral groundwater pH. The pre-injection arsenic concentrations ranged from 0.19 to 105 µg/L. The upper end of this range is elevated relative to arsenic concentrations observed in wells outside of the barrier wall. Arsenic concentrations decreased during pilot-scale testing to levels below the PRG in MW-53, MW-54, and the injection well, but remained above the PRG for IMW-A1-D. In MW-53, the arsenic concentration was initially 22.9 µg/L which is similar to the highest concentrations measured in wells outside of the barrier wall in MW-43/44; after $CO_2$ injection the arsenic concentration decreased to 8.54 µg/L, suggesting that $CO_2$ injection may be able to reduce the arsenic concentration in groundwater to levels below the PRG.

Pre-injection chromium concentrations ranged from 0.4 to 683 µg/L. This range is consistent with the chromium concentrations in wells outside of the barrier wall. Chromium concentrations decreased during pilot-scale testing to levels below the PRG in MW-53, MW-54, and the injection well. Concentrations also decreased but remained above the PRG for IMW-A1-D; $CO_2$ injection may be able to reduce the chromium concentration in groundwater to levels below the PRG.

A summary of how other analytes affected by $CO_2$ injections is presented below:

- Aluminum—Pre-injection aluminum concentrations ranged from 90 to 9,970 µg/L. This range is consistent with the aluminum concentrations of wells outside of the barrier wall. Aluminum concentrations decreased during pilot-scale testing, but remained above the PRG.

- Lead—Pre-injection lead concentrations ranged from 0.9 to 25.8 µg/L. A lead concentration of 25.8 µg/L is greater than what has historically been measured in wells outside of the barrier wall. Lead concentrations decreased during pilot-scale testing to levels below the PRG in all monitoring wells.
- Vanadium—Pre-injection vanadium concentrations ranged from 0.3 to 4,120 µg/L. A vanadium concentration of 4,120 µg/L is greater than what has historically been measured in wells outside of the barrier wall. Vanadium concentrations decreased during pilot-scale testing to levels slightly above the PRG in all wells except MW-54. The vanadium concentration in MW-54 increased to a value slightly above the PRG.
- Iron—The iron concentrations in MW-53, MW-54, and the injection well increased during pilot-scale testing; the iron concentration in IMW-A1-D decreased during pilot-scale testing.
- Manganese—The manganese concentration in MW-53, MW-54, and the injection well increased during pilot-scale testing; the manganese concentration in IMW-A1-D decreased during pilot-scale testing.
- Silica-Silica was determined to be supersaturated in several wells impacted by high pH. Precipitation as the pH of the groundwater is neutralized is of concern as amorphous silica could cause injection well fouling and alter aquifer characteristics, complicating scaled-up neutralization. The dissolved silica concentration decreased by two orders of magnitude for all wells screened in the LAZ. Figure 47 plots the results for dissolved silica versus pH for groundwater samples collected from wells screened in the LAZ during pilot testing. The figure compares samples collected against equilibrium modeling of MW-44 (model methodology presented in the work plan). The model predictions for the equilibrium dissolved silica concentration compare well with the samples collected during pilot testing.
- Sulfide—Sulfide concentrations decreased in all the wells to below the reporting limit, except for IMW-A1-D, where the sulfide concentration decreased from 112 mg/L to 18.7.
- Alkalinity—Groundwater alkalinity increased in MW-54, the injection well, IMW-A2-S, IMW-A2-D, IMW-B2-S, the vent well, and IMW-C1-S; the groundwater alkalinity decreased in IMW-B1-D and IMW-A1-D. These results are consistent with groundwater bench-scale testing results, which showed a slight increase in alkalinity upon titration to 6.5 SU.

Due to varying conditions in soil and groundwater chemistry at the site, results may vary depending on location, groundwater chemistry, and soil properties. there results show that $CO_2$ injection may have a beneficial impact on other site wide COCs in addition to groundwater pH neutralization.

### 4.8.2 Conclusions

Pilot-scale testing yielded the following findings regarding Objective 8.

- Neutralization of high pH groundwater decreased arsenic, copper, chromium, vanadium, and aluminum concentration in groundwater to levels near the PRG at the site.
- Dissolved silica concentrations in groundwater generally decreased during neutralization, but precipitation of amorphous silica did not impact aquifer characteristics.

These results indicate that $CO_2$ injections alone may support cleanup of site COCs in addition to neutralization of groundwater.

# 5.0 Technology evaluation

The purpose of the pilot study was to assess $CO_2$ injection for inclusion into the CMS for the site. Based on bench testing and pilot testing results, injection of gaseous $CO_2$ for neutralizing high pH groundwater is technically feasible. Neutralization objectives were achieved within the areas described above. In addition, $CO_2$ injection in general resulted in lower concentrations for COCs for site presented in the CMS WP. A summary of the pilot study for consideration and incorporation into the CMS is provided below.

- While a groundwater titration curve can be used to estimate acid demand of groundwater, groundwater chemistry, $CO_2$ utilization efficiency, and soil properties will ultimately determine the mass of $CO_2$ required to neutralize a unit volume of soil and groundwater.
- The relationship between the average injection pressure and the $CO_2$ flow rate is approximately linear.
- At an injection pressure of 26 psi, the ROI for the injection well is approximately 15 feet.
- The ROI increased as injection pressure increased.
- During full-scale injections, groundwater 20 feet from the injection well experienced an increase in dissolved TIC, but not enough $CO_2$ was received to neutralize groundwater to the target pH of 8.5 SU.
- Injection cycles consisting of 2 hours of active injection and 1 hour of rebound was effective at promoting groundwater mixing while minimizing the upward displacement of high pH groundwater.
- Mounding was greater between the barrier wall and the injection well; however, it is uncertain whether this is due to the barrier wall or soil heterogeneity.
- Injection of $CO_2$ caused the upward displacement of high pH groundwater from the LAZ to the UAZ.
- Generation of hydrogen sulfide occurred and is expected during full-scale injections. Therefore, air quality monitoring should be included to monitor for potentially adverse impacts on human health and the environment.
- The soil has a low rebound capacity; therefore, the initial groundwater neutralization at the site is likely permanent.
- Approximately 20,115 pounds of $CO_2$ over 26 injection events was required to neutralize all groundwater within a 10- to 20-foot radius of an injection well (throughout Phase 1 and 3).
- An average of 5,100 pounds of $CO_2$ was required to reduce the groundwater pH by one standard pH unit within 10 feet of the injection well (throughout Phase 1 and 3).
- The rate of groundwater neutralization slowed during pilot-scale testing.
- A conservative $CO_2$ utilization efficiency of 5.4% should be assumed for the design of neutralizing the high pH target area.
- $CO_2$ utilization efficiency decreased across multiple injections.
- The precipitation of amorphous silica and other solids did not affect aquifer characteristics.
- Neutralization of high pH groundwater decreased arsenic, copper, aluminum, vanadium, and chromium concentrations in groundwater to levels near the respective PRGs for the site.

While pilot testing confirmed the technical feasibility of injecting $CO_2$ for neutralizing high pH groundwater, the technology's suitability for scaled-up neutralization of the high pH target area and disproportionate costs need to be evaluated in parallel with other site remediation action objectives to determine the most effective remediation plan. Further discussion on the selection of technologies will be presented in the revised CMS.

# 6.0 References

Amec Environment & Infrastructure, Inc. (AMEC), 2012. Shoreline Soil and Groundwater Characterization Data Report, Former Rhone-Poulenc Site, Tukwila, Washington, March.

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———. 2016b. Quality Assurance Project Plan, Former Rhone Poulenc Site, Tukwila, Washington, July.

U.S. Army Corps of Engineers, 2013. In-Situ Air Sparging, Engineer Manual, EM 200-1-19, 31 December.

Wood Environment & Infrastructure Solutions, Inc (Wood), 2018. $CO_2$ Neutralization Pilot Study Phase I and II Summary of Results and Phase III Work Plan Update, Former Rhone Poulenc Site, Tukwila, Washington, September.

# Tables

**TABLE 1: PILOT STUDY WELLS pH, TOTAL ALKALINITY, AND TOTAL DISSOLVED SILICON**

Former Rhone-Poulenc Site, Tukwila, WA

| Well[1,2,3] | pH (min) (SU) | pH (avg) (SU) | pH (max) (SU) | Total Alkalinity (min) (mg/L $CaCO_3$) | Total Alkalinity (avg) (mg/L $CaCO_3$) | Total Alkalinity (max) (mg/L $CaCO_3$) | Silicon (min) (mg/L) | Silicon (avg) (mg/L) | Silicon (max) (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| **HCIM Area Wells** | | | | | | | | | |
| MW-29 | 6.43 | 6.57 | 6.78 | 234 | 280.4 | 427 | 39.9 | 43.7 | 46.4 |
| MW-53 | 7.48 | -- | 10.79 | -- | -- | 1000 | -- | -- | 224 |
| MW-54 | 9.71 | -- | 10.52 | -- | -- | 1030 | -- | -- | 3870 |
| **Shoreline Area Wells** | | | | | | | | | |
| MW-43 | 9.02 | 10.68 | 11.36 | 1800 | 1932.5 | 2020 | 214 | 324.5 | 391 |
| MW-44 | 9.05 | 10.63 | 11.26 | 2540 | 2717.5 | 2980 | 628 | 642.5 | 667 |

Notes

1. For wells with less than three sample results, no average is calculated and only a min and max are shown. For wells with only one analysis, the result is presented as the maximum.
2. pH data are for groundwater monitoring and sampling from March 2008 to September 2017.
3. The total alkalinity and silicon data for MW-53 and MW-54 represent a single monitoring event conducted in 2014. The silicon and alkalinity data for MW-29 include both the 2014 monitoring event and four 2005 quarterly sampling events.

Abbreviations

avg = average

$CaCO_3$ = calcium carbonate equivalents

HCIM = hydraulic control interim measure

max = maximum

min = minimum

mg/L = milligrams per liter

SU = standard unit

**TABLE 2: PERFORMANCE MONITORING ROUND 28 WATER CHEMISTRY DATA[1,2]**

Former Rhone-Poulenc Site, Tukwila, WA

| Well ID | Laboratory $pH^3$ | Total Alkalinity (mg/L $CaCO_3$) | Total Silicon (mg/L) | Cations | | | | | Anions | | | | Total Metals | | | | | $T_P$ | $T_N$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Sodium (mg/L) | Potassium (mg/L) | Calcium (mg/L) | Magnesium (mg/L) | Iron (mg/L) | $Cl^-$ (mg/L) | $SO_4^{2-}$ (mg/L) | $HS^-$ (mg/L) | $NO_2^{2-}$ (mg-N/L) | Manganese (mg/L) | Vanadium (mg/L) | Chromium (mg/L) | Aluminum (mg/L) | Copper (mg/L) | (mg/L) | (mg/L) |
| MW-28 | 10.58 | 1,460 | 320 | 476 | 26.3 | 4.38 | 0.45 | 5.6 | 12.5 | 122 | 4.01 | 0.125 | 0.178 | 0.047 | 0.010 | 0.89 | 0.069 | 2.30 | 0.125 |
| MW-28 Dup | 10.58 | 1,460 | 324 | 499 | 27.3 | 3.82 | 0.3 | 3.8 | 12.5 | 120 | 4.39 | 0.125 | 0.118 | 0.044 | 0.010 | 0.88 | 0.072 | 2.49 | 0.125 |
| MW-38 | 6.72 | 342 | 30.5 | 107 | 5 | 17.9 | 18.7 | 21.5 | 35.9 | 165 | 0.05 | 0.05 | 1.060 | 0.032 | 0.007 | 0.37 | 0.006 | 1.95 | 0.05 |
| MW-39 | 7.58 | 682 | 22.1 | 533 | 20.3 | 5.45 | 9.41 | 3.1 | 531 | 263 | 0.05 | 0.100 | 0.062 | 0.025 | 0.010 | 0.89 | 0.011 | 13.8 | 0.100 |
| DM-5 | 7.34 | 1,430 | 24 | 509 | 5.3 | 13.8 | 10.8 | 10.6 | 53.2 | 576 | 0.05 | 0.25 | 0.147 | 0.457 | 0.112 | 3.06 | 0.026 | 18.6 | 0.25 |
| MW-27 | 10.07 | 2,400 | 271 | 1,440 | 63.4 | 2.36 | 0.34 | 0.8 | 10 | 977 | 4.1 | 0.100 | 0.017 | 0.050 | 0.003 | 2.11 | 0.084 | 1.36 | 0.10 |
| MW-29 | 6.68 | 234 | 43.5 | 64 | 3.6 | 19.7 | 10.1 | 27.0 | 10.0 | 65 | 0.050 | 0.100 | 1.810 | 0.003 | 0.003 | 0.15 | 0.003 | 0.932 | 0.47 |
| MW-42 | 7.71 | 696 | 18.6 | 521 | 20 | 7.72 | 9.21 | 1.6 | 546 | 98 | 0.050 | 0.125 | 0.092 | 0.031 | 0.013 | 6.39 | 0.022 | 19.0 | 1.26 |
| DM-8 | 6.96 | 256 | 25.7 | 330 | 8.0 | 19.2 | 9.11 | 13.0 | 232 | 435 | 0.050 | 0.125 | 1.430 | 0.059 | 0.009 | 0.89 | 0.013 | 6.24 | 0.125 |
| MW-41 | 10.07 | 1,300 | 123 | 782 | 8.0 | 10.9 | 11.3 | 2.0 | 747 | 400 | 22.4 | 0.25 | 0.071 | 0.314 | 0.072 | 1.37 | 0.132 | 7.03 | 0.25 |
| MW-41 Dup | 10.11 | 1,330 | 126 | 875 | 8.4 | 11.5 | 11.1 | 2.1 | 724 | 383 | 19 | 0.25 | 0.071 | 0.359 | 0.076 | 1.44 | 0.139 | 8.32 | 0.25 |
| MW-40 | 7.75 | 686 | 20.2 | 1,710 | 58.7 | 62.6 | 149 | 0.1 | 3650 | 102 | 1.18 | 0.025 | 0.118 | 0.008 | 0.003 | 0.49 | 0.016 | 15.00 | 0.025 |
| MW-17 | 7.17 | 1,390 | 21.2 | 538 | 6.1 | 26.6 | 5.18 | 9.0 | 25 | 455 | 0.37 | 0.25 | 1.400 | 0.486 | 0.071 | 2.65 | 0.024 | 18.7 | 0.987 |
| MW-43 | 10.34 | 2,020 | 336 | 939 | 18.9 | 11 | 0.32 | 1.8 | 411 | 451 | 7.5 | 0.25 | 0.010 | 0.390 | 0.074 | 1.21 | 0.044 | 29.6 | 0.526 |
| MW-44 | 10.98 | 2,980 | 668 | 859 | 8.3 | 8.44 | 1.36 | 6.8 | 74.3 | 161 | 14.5 | 0.125 | 0.196 | 0.310 | 0.033 | 1.21 | 0.131 | 1.84 | 0.125 |
| MW-45 | 7.67 | 662 | 19.9 | 366 | 15.3 | 4.95 | 5.31 | 2.4 | 359 | 94 | 0.05 | 0.125 | 0.107 | 0.030 | 0.010 | 3.97 | 0.019 | 17.4 | 0.125 |
| MW-46 | 6.5 | 391 | 26.3 | 219 | 13.9 | 58.1 | 37.7 | 34.0 | 365 | 27 | 0.05 | 0.05 | 1.240 | 0.011 | 0.003 | 0.05 | 0.002 U | 1.08 | 0.05 |
| EX-3 | 6.82 | 474 | 27.5 | 197 | 7.1 | 13.7 | 12.8 | 26.3 | 12.5 | 233 | 0.05 | 0.125 | 1.070 | 0.046 | 0.009 | 0.1 | 0.003 | 2.92 | 0.13 |
| B1A | 6.31 | 112 | 18.3 | 33 | 3.3 | 9.84 | 5.48 | 8.9 | 2.5 | 28 | 0.05 | 0.005 | 0.250 | 0.002 | 0.003 | 0.12 | 0.002 U | 0.162 | 0.011 |

Notes

1. Round 28 sampling event data for samples collected June 14–16, 2005.
2. Data qualifiers:
   U = analyte not detected at or above laboratory reporting limit shown.
3. Laboratory pH was measured during alkalinity analysis for each sample.

Abbreviations

$CaCO_3$ = calcium carbonate equivalents
$Cl^-$ = chloride
Dup = Duplicate sample
$HS^-$ = bisulfide
mg/L = milligrams per liter
mg-N/L = milligrams as nitrogen per liter
$NO_2^{2-}$ = nitrite
$SO_4^{2-}$ = sulfate
$T_N$ = Total nitrogen
$T_P$ = Total phosphorous

**TABLE 3: $CO_2$ PILOT STUDY DATA QUALITY OBJECTIVES**

Former Rhone-Poulenc Site, Tukwila, WA

| Pilot Study Component | | Monitoring Point(s) | Medium | Objectives[1] | How Data were Intended to Meet the Objectives | Location Explanation |
|---|---|---|---|---|---|---|
| Aquifer Slug Testing | Baseline Testing | Injection well, MW-53, MW-54, and IMW-A1-D | GW | 7 | Falling head and rising head slug testing to estimate baseline hydraulic conductivity within the vicinity of the injection well to assess changes to hydraulic conductivity of saturated zone. | Locations selected within the immediate vicinity (10 feet) of the injection location. It is expected that measurable effects would be observed within the immediate vicinity of the injection well. |
| | Completion of Phase 3 Field Testing | Injection well, MW-53, MW-54, and IMW-A1-D | GW | 7 | Falling head and rising head slug testing after Phase 3 neutralization to assess changes in hydraulic conductivity due to $CO_2$ injection. | |
| Bench Scale Testing | Groundwater Chemistry | Injection well | GW | 1, 6, 7, 8 | Groundwater titration with acid on representative groundwater sample to assess potential for solids precipitation/dissolution (changes in concentrations of TDS and silica). Groundwater alkalinity results were compared to the model predictions and may be used to adjust estimated $CO_2$ mass requirements for field testing. | The injection well was placed in the highest pH area expected to be encountered within the HCIM area and is expected to be representative of worst-case groundwater and soil. The injection well location is based on groundwater data from monitoring wells (i.e., MW-53 and MW-54) with characteristics similar to target areas outside the wall (i.e., MW-43 and MW-44). The distance from the barrier wall is based on the anticipated ROI and the likely injection well placement in the Shoreline Area if $CO_2$ neutralization is selected in the CMS for implementation as part of the site remediation. |
| | Soil Buffering Capacity | Injection well | Soil | 1 | Soil buffering capacity, as measured through the change in pH in de-ionized water in contact with soil samples, were used to estimate the acid demand to neutralize the aquifer matrix. The acid demand was measured as an equivalence of acid required to neutralize a gram/kilogram of soil for the soil types tested. Based on this measurement and results from the field study for $CO_2$ utilization efficiency, an estimate was made for the total amount of $CO_2$, the number of injection events, and the time required to neutralize the aquifer matrix. It is anticipated that for each round of injection, geochemical conditions within the soil matrix may cause the groundwater pH to rebound until the source of the high pH in the aquifer matrix is exhausted. | |
| Field Testing | Phase 1 | Injection well, MW-29, MW-53, and MW-54, All observation wells, Vent well | GW/Well Head | 2, 3, 4, 6, 8 | Phase 1 testing and monitoring were designed to provide information to assess the following:<br>• The optimum injection flow rate (through measurements of influent $CO_2$ injection rates and pressures coupled with ROI measurements and utilization measurements);<br>• The characteristics of the mound formation and collapse (as indicated by water level and pressure measurements in the observation wells) for various injection rates (which may be used in support of the final plan for Phase 3 testing);<br>• The ROI (through wellhead pressure measurements, water levels, and TIC/alkalinity groundwater chemistry measurements [for changes in total carbonate species]); and<br>• $CO_2$ utilization efficiency (through monitoring $CO_2$ injection volumes and changes in groundwater TIC and alkalinity to estimate the mass of $CO_2$ delivered and available for neutralization of groundwater). | Observation wells and monitoring wells selected based on proximity to injection well. Depths selected based on injection depth and anticipated distribution of $CO_2$ in the aquifer during injections. |

**TABLE 3: $CO_2$ PILOT STUDY DATA QUALITY OBJECTIVES**

Former Rhone-Poulenc Site, Tukwila, WA

| Pilot Study Component | | Monitoring Point(s) | Medium | Objectives[1] | How Data were Intended to Meet the Objectives | Location Explanation |
|---|---|---|---|---|---|---|
| Field Testing Continued | Phase 2 | Injection well, MW-29, MW-53, and MW-54, All observation wells, Vent well | GW | 5, 8 | Rebound monitoring during Phase 2 included sample collection for general chemistry parameters to assess changes in geochemistry as a result of Phase 1 $CO_2$ injections. In addition, pH rebound was assessed by monitoring pH in the monitoring wells, the injection well, and observation wells during the rebound period and the data was used to assess the kinetics of pH rebound to estimate neutralization time requirements. | The observation and monitoring wells monitored as part of Phase 2 were all within the anticipated ROI. |
| Field Testing Continued | Phase 3 | Injection well, MW-29, MW-53, and MW-54, All observation wells, Vent well | GW/Wellhead | 1, 3, 4, 5, 6, 7, 8 | Field injections during Phase 3 helped to assess the objectives outlined in Section 2.0 in the Pilot Study Work Plan.<br>The amount of $CO_2$ required to be injected to neutralize high pH in the subsurface (soil and groundwaterwas assessed through mass balances on $CO_2$ delivered to the aquifer and measured changes in TIC in groundwater samples upon meeting neutralization objectives described in Section 4.0. The estimated $CO_2$ mass required for groundwater neutralization was coupled with the total $CO_2$ mass requirements for soil estimated from the bench testing to determine how many injection events were required to meet neutralization objectives for the site (i.e., neutralization of both soil and groundwater).<br>The ROI was assessed based on changes in TIC/alkalinity measurements in the observation wells, water levels, and pressure readings in the wellheads and refined from the Phase 1 approximation of the ROI; the ROI was used in the CMS to estimate the number of wells required to neutralize the affected portions of the Shoreline Area.<br>The characteristics of mound formation/collapse and effects of mounding on mixing and ROI during injections was assessed by monitoring water levels and pressure readings in wellheads and using TIC/alkalinity measurements from observation wells; these data was used collectively to assess the ROI.<br>Kinetics of pH neutralization were evaluated by monitoring the rate of change in pH during active injections and during periods between active injections as $CO_2$ dissolved in the groundwater; these data was used to assess time required for neutralization.<br>$CO_2$ utilization efficiency may be estimated based on TIC/alkalinity measurements and the total mass of $CO_2$ delivered to the aquifer; these data were used to assess $CO_2$ requirements.<br>Analysis of post-injection groundwater samples were used to assess changes in geochemistry from comparisons to baseline samples collected during Phase 1; these data were used to assess changes in groundwater chemistry, including contaminant concentrations, caused by $CO_2$ injection. | Observation wells and monitoring wells selected based on proximity to injection well. Depths selected based on injection depth and anticipated distribution of $CO_2$ in the aquifer during injections. |
| Field Testing Continued | Phase 4 | Injection well, MW-29, MW-53 and MW-54, All observation wells, Vent well | GW | 5, 8 | Rebound monitoring during Phase 4 included sample collection for general chemistry parameters to assess changes in geochemistry as a result of pH rebound after Phase 3 $CO_2$ neutralization injections have been completed. In addition, pH rebound was assessed by monitoring pH in the monitoring wells, the injection well, and observation wells during the rebound monitoring period. The pH rebound data were used in the CMS to estimate the time needed for neutralization of the Shoreline Area. | The observation and monitoring wells monitored as part of Phase 4 were all within the anticipated ROI. |

Notes:

The objectives are as follows:

1. Estimate the amount of $CO_2$ that would be consumed to neutralize high pH groundwater and soil in contact with the high pH groundwater.
2. Assess $CO_2$ injection rates within the site.
3. Estimate the practical ROI for $CO_2$ injection wells.
4. Evaluate the effect on the formation and collapse of groundwater mounding caused by injection of gaseous $CO_2$.
5. Evaluate the kinetics of high pH groundwater neutralization and pH rebound.
6. Evaluate the $CO_2$ utilization efficiency and $CO_2$ consumption required to neutralize high pH groundwater and soil in the field.
7. Evaluate potential changes in aquifer characteristics that may result from $CO_2$ injection.
8. Evaluate changes in geochemistry and other parameters that may result from $CO_2$ injection.

Abbreviations:

CMS = Corrective Measures Study
$CO_2$ = carbon dioxide
GW = groundwater
HCIM = hydraulic control interim measure
ROI = radius of influence
TDS = total dissolved solids
TIC = total inorganic carbon

**TABLE 4: PILOT STUDY AREA AND HIGH pH SHORELINE AREA WELL DETAILS**

Former Rhone-Poulenc Site, Tukwila, WA

| Well | Depth of Well[1] (feet bgs) | Screen Length[2] (feet) | Well Diameter (inches) | Distance from Injection Well (feet) | Initial pH (SU) | Vertical Distance from Injection Well Screen[3] (feet) |
|---|---|---|---|---|---|---|
| **Shoreline Area High pH Wells** | | | | | | |
| MW-43 | 61.3 | 10 | 2 | 45 | 10.80 | -16 |
| MW-44 | 41.6 | 10 | 2 | 43 | 10.75 | 4 |
| **Pilot Study Injection Wells** | | | | | | |
| Injection Well | 50.3 | 5.0 | 2 | -- | 11.90 | -- |
| **Pilot Study Observation Wells** | | | | | | |
| IMW-A1-D | 49.9 | 5.0 | 2 | 10 | 11.89 | -5 |
| IMW-B1-S | 35.2 | 10.0 | 2 | 20 | 7.65 | 10 |
| IMW-B1-D | 49.9 | 5.0 | 2 | 20 | 12.04 | -5 |
| IMW-C1-S | 27.8 | 10.0 | 2 | 30 | 6.72 | 18 |
| IMW-A2-S | 35.4 | 10.0 | 2 | 10 | 7.18 | 10 |
| IMW-A2-D | 49.9 | 5.0 | 2 | 10 | 11.69 | -5 |
| IMW-B2-S | 27.3 | 10.0 | 2 | 20 | 6.59 | 18 |
| MW-29 | 21.1 | 15.0 | 2 | 31 | 6.64 | 24 |
| MW-53 | 40 | 10 | 2 | 7 | 11.07 | 5 |
| MW-54 | 60 | 10 | 2 | 10 | 7.07 | -15 |
| Vent Well | 25.2 | 15.2 | 2 | 10 | 6.74 | 20 |

Notes

1. Depth to bottom of well is the total depth from the ground surface to the bottom of the well's screen.
2. Screen length is the total length of the well screen.
3. Vertical distance from well screen is the difference in elevation from the top of the new injection well screen to the bottom of the designated well. A negative value means that the bottom of the designated well is deeper than the top of the new injection well screen.

Abbreviations

bgs = below ground surface

SU = standard pH units

## TABLE 5: SLUG TEST CONDITIONS AND AQTESOLV INPUTS

Former Rhone-Poulenc Site, Tukwila, WA

| Parameter | Injection Well | | | | IMW-A1-D | | | |
|---|---|---|---|---|---|---|---|---|
| Pre/Post injection | Pre injection | | Post injection | | Pre injection | | Post injection | |
| Slug in/out | Slug in | Slug out | Slug in | Slug out | Slug in | Slug out | Slug in | Slug out |
| Initial displacement (ft) | 2.67 | 2.76 | 2.05 | 2.33 | 2.71 | 2.76 | 3.25 | 3.35 |
| Water column height (ft) | 34.17 | 34.19 | 37.39 | 37.46 | 33.46 | 35.16 | 33.50 | 36.61 |
| Radius of casing (ft) | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 |
| Radius of filter pack (ft) | 0.25 | 0.25 | 0.25 | 0.25 | 0.16 | 0.16 | 0.16 | 0.16 |
| Depth to top of screen (ft) | 42.86 | 42.86 | 42.86 | 42.86 | 42.48 | 42.48 | 42.48 | 42.48 |
| Length of screen (ft) | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Depth of transducer (ft) | 31.58 | 31.58 | 30.82 | 30.82 | 31.72 | 31.72 | 29.52 | 29.52 |

| Parameter | MW-53 | | | | MW-54 | | | |
|---|---|---|---|---|---|---|---|---|
| Pre/Post injection | Pre injection | | Post injection | | Pre injection | | Post injection | |
| Slug in/out | Slug in | Slug out | Slug in | Slug out | Slug in | Slug out | Slug in | Slug out |
| Initial displacement (ft) | 0.56 | 0.79 | 0.96 | 0.93 | 2.42 | 2.56 | 2.86 | 2.95 |
| Water column height (ft) | 24.58 | 24.60 | 24.68 | 24.67 | 45.41 | 45.74 | 44.88 | 45.05 |
| Radius of casing (ft) | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 |
| Radius of filter pack (ft) | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 |
| Depth to top of screen (ft) | 28.00 | 28.00 | 28.00 | 28.00 | 48.00 | 48.00 | 48.00 | 48.00 |
| Length of screen (ft) | 12.00 | 12.00 | 12.00 | 12.00 | 12.00 | 12.00 | 12.00 | 12.00 |
| Depth of transducer (ft) | 31.56 | 31.56 | 34.15 | 34.15 | 57.71 | 57.71 | 34.18 | 34.18 |

Abbreviations

ft = feet

sec = seconds

**TABLE 6: $CO_2$ INJECTION FIELD STUDY MONITORING PLAN**

Former Rhone-Poulenc Site Tukwila, Washington

| Monitoring Event | Monitoring Location | Media | Pressure | Water Levels | Field Parameters[1] | Temperature and pH[2] | Alkalinity | Total Suspended Solids | Total Dissolved Solids[3] | Total Metals[4] | Dissolved Metals[3,5] | Dissolved Silica[3] | Dissolved Total Inorganic Carbon[3,6] | Anions[7] | Cations[8] | Sulfide |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analytical Method | | | Gauge/ Transducer | Transducer/ Manual | field sampler | lab or field probe | SM 2320 B-97 | SM 2540 | SM 2540 | EPA 6020 | EPA 6020 | EPA 6020 | SM 5310B | EPA 300.0 | EPA 6010 | SM 4500-S2 |
| Bottle requirements | | | -- | -- | -- | -- | 500 mL HDPE[9] | 1 L HDPE | 1 L HDPE | 500 mL HDPE | 500 mL HDPE | 500 mL HDPE | 40-mL vial[9] | 500 mL HDPE | 500 mL HDPE | 500 mL HDPE[9] |
| Preservative | | | -- | -- | -- | -- | <6°C | <6°C | <6°C | pH < 2 with 1:1 $HNO_3$; <6°C | pH < 2 with 1:1 $HNO_3$; <6°C | pH < 2 with 1:1 $HNO_3$; <6°C | <6°C | <6°C | pH < 2 with 1:1 $HNO_3$; <6°C | 2 mL 1N Zinc acetate + 1 mL 10N NaOH pH>9 |
| Hold Time | | | -- | -- | -- | -- | 14 days | 7 days | 7 days | 6 months | 6 months | 6 months | 28 days | 48 hours | 6 months | 7 days |
| Reporting Limit Goals | | | -- | -- | -- | -- | 1 mg/L $CaCO_3$ | 1 mg/L | 5 mg/L | - | - | 0.06 mg/L | 0.5 mg/L | 0.1 mg/L | - | 0.05 mg/L |
| Aquifer Slug Testing Baseline | Injection Well | GW | X | X | | | | | | | | | | | | |
| | IMW-A1-D | GW | X | X | | | | | | | | | | | | |
| | MW-53 | GW | X | X | | | | | | | | | | | | |
| | MW-54 | GW | X | X | | | | | | | | | | | | |
| Groundwater Chemistry Bench Study | Injection Well-Baseline | GW | | | X | X | X | X | X | | | X | | | | |
| | Neutralized Groundwater | GW | | | | X | X | X | X | | | X | | | | |
| Field Pilot Study Phase 1 Baseline Testing | Injection Well | GW | | | X | | X | X | X | X | X | X | X | X | X | X |
| | IMW-A1-D | GW | | | X | | X | X | X | X | X | X | X | X | X | X |
| | IMWs | GW | | | X | | X | X | X | | | X | X | | | |
| | MW-29 | GW | | | X | | X | X | X | | | X | X | | | |
| | MW-53 | GW | | | X | | X | X | X | X | X | X | X | X | X | X |
| | MW-54 | GW | | | X | | X | X | X | X | X | X | X | X | X | X |
| | Vent Well | GW | | | X | | X | X | X | | | X | X | X | X | X |
| Field Pilot Study - Phase 1 Injection Run Monitoring | Injection well | GW | X | | | | | | | | | | | | | |
| | IMWs | GW | X | X | | X | | | | | | | | | | |
| | MW-29 | GW | X | X | | X | | | | | | | | | | |
| | MW-53 | GW | X | X | | X | | | | | | | | | | |
| | MW-54 | GW | X | X | | X | | | | | | | | | | |
| | Vent Well | GW | X | X | | X | | | | | | | | | | |
| Field Pilot Study - Phase 1 Post Injection (each pressure) Monitoring | IMWs | GW | | | X | | X | | X | | | X | X | | | |
| | MW-29 | GW | | | X | | X | | X | | | X | X | | | |
| | MW-53 | GW | | | X | | X | | X | | | X | X | | | |
| | MW-54 | GW | | | X | | X | | X | | | X | X | | | |
| | Vent Well | GW | | | X | | X | | X | | | X | X | | | |
| Field Pilot Study - Phase 1 Post Injection | Injection Well | GW | | | X | | X | X | X | | | X | X | X | X | X |
| | IMW-A1-D | GW | | | X | | X | X | X | | | X | X | X | X | X |
| | IMWs | GW | | | X | | X | X | X | | | X | X | | | |
| | MW-29 | GW | | | X | | X | X | X | | | X | X | | | |
| | MW-53 | GW | | | X | | X | X | X | | | X | X | X | X | X |
| | MW-54 | GW | | | X | | X | X | X | | | X | X | X | X | X |
| | Vent Well | GW | | | X | | X | X | X | | | X | X | X | X | X |
| Field Pilot Study -Phase 2 Rebound Monitoring | IMWs | GW | | X | | X | | | | | | | | | | |
| | Injection well | GW | | X | | X | | | | | | | | | | |
| | MW-29 | GW | | X | | X | | | | | | | | | | |
| | MW-53 | GW | | X | | X | | | | | | | | | | |
| | MW-54 | GW | | X | | X | | | | | | | | | | |
| | Vent Well | GW | | X | | X | | | | | | | | | | |
| Field Pilot Study - Phase 2 Post Rebound | Injection Well | GW | | | X | | X | X | X | | | X | X | X | X | X |
| | IMW-A1-D | GW | | | X | | X | X | X | | | X | X | X | X | X |
| | IMWs | GW | | | X | | X | X | X | | | X | X | | | |
| | MW-29 | GW | | | X | | X | X | X | | | X | X | | | |
| | MW-53 | GW | | | X | | X | X | X | | | X | X | X | X | X |
| | MW-54 | GW | | | X | | X | X | X | | | X | X | X | X | X |
| | Vent Well | GW | | | X | | X | X | X | | | X | X | X | X | X |

**TABLE 6: $CO_2$ INJECTION FIELD STUDY MONITORING PLAN**

Former Rhone-Poulenc Site Tukwila, Washington

| Monitoring Event | Monitoring Location | Media | Pressure | Water Levels | Field Parameters[1] | Temperature and pH[2] | Alkalinity | Total Suspended Solids | Total Dissolved Solids[3] | Total Metals[4] | Dissolved Metals[3,5] | Dissolved Silica[3] | Dissolved Total Inorganic Carbon[3,6] | Anions[7] | Cations[8] | Sulfide |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Analytical Method | Gauge/ Transducer | Transducer/ Manual | field sampler | lab or field probe | SM 2320 B-97 | SM 2540 | SM 2540 | EPA 6020 | EPA 6020 | EPA 6020 | SM 5310B | EPA 300.0 | EPA 6010 | SM 4500-S2 |
| | | Bottle requirements | -- | -- | -- | -- | 500 mL HDPE[9] | 1 L HDPE | 1 L HDPE | 500 mL HDPE | 500 mL HDPE | 500 mL HDPE | 40-mL vial[9] | 500 mL HDPE | 500 mL HDPE | 500 mL HDPE[9] |
| | | Preservative | -- | -- | -- | -- | <6°C | <6°C | <6°C | pH < 2 with 1:1 $HNO_3$; <6°C | pH < 2 with 1:1 $HNO_3$; <6°C | pH < 2 with 1:1 $HNO_3$; <6°C | <6°C | <6°C | pH < 2 with 1:1 $HNO_3$; <6°C | 2 mL 1N Zinc acetate + 1 mL 10N NaOH pH>9 |
| | | Hold Time | -- | -- | -- | -- | 14 days | 7 days | 7 days | 6 months | 6 months | 6 months | 28 days | 48 hours | 6 months | 7 days |
| | | Reporting Limit Goals | -- | -- | -- | -- | 1 mg/L $CaCO_3$ | 1 mg/L | 5 mg/L | - | - | 0.06 mg/L | 0.5 mg/L | 0.1 mg/L | - | 0.05 mg/L |
| Field Pilot Study -Phase 3 Pulsed Injection Run Monitoring | Injection Manifold | Gas | X | | | | | | | | | | | | | |
| | IMWs | GW | X | X | | X | | | | | | | | | | |
| | IMW-C1-S | GW | X | X | | | | | | | | | | | | |
| | MW-29 | GW | X | X | | | | | | | | | | | | |
| | MW-53 | GW | X | X | | X | | | | | | | | | | |
| | MW-54 | GW | X | X | | | | | | | | | | | | |
| | Vent Well | GW | X | X | | | | | | | | | | | | |
| Field Pilot Study - Phase 3 Post Injection Monitoring | Injection Well | GW | | X | X | | X | X | X | X | X | X | X | X | X | X |
| | IMW-A1-D | GW | | X | X | | X | X | X | X | X | X | X | X | X | X |
| | IMWs | GW | | X | X | | X | X | X | | | X | X | | | |
| | MW-29 | GW | | X | X | | X | X | X | | | X | X | | | |
| | MW-53 | GW | | X | X | | X | X | X | X | X | X | X | X | X | X |
| | MW-54 | GW | | X | X | | X | X | X | X | X | X | X | X | X | X |
| | Vent Well | GW | | X | X | | X | X | X | | | X | X | X | X | X |
| Aquifer Slug Testing Post Injections | Injection Well | GW | X | X | | | | | | | | | | | | |
| | IMW-A1-D | GW | X | X | | | | | | | | | | | | |
| | MW-53 | GW | X | X | | | | | | | | | | | | |
| | MW-54 | GW | X | X | | | | | | | | | | | | |
| Field Pilot Study -Phase 4 Rebound Monitoring | Injection well | GW | | X[10] | | X | | | | | | | | | | |
| | IMWs | GW | | X[10] | | X | | | | | | | | | | |
| | IMW-C1-S | GW | | | | | | | | | | | | | | |
| | MW-29 | GW | | | | | | | | | | | | | | |
| | MW-53 | GW | | X[10] | | X | | | | | | | | | | |
| | MW-54 | GW | | | | | | | | | | | | | | |
| | Vent Well | GW | | | | | | | | | | | | | | |
| Field Pilot Study -Phase 4 Post-Neutralization Monitoring | Injection Well | GW | | | X | | X | X | X | X | X | X | X | X | X | X |
| | IMW-A1-D | GW | | | X | | X | X | X | X | X | X | X | X | X | X |
| | IMWs | GW | | | X | | X | X | X | | | X | X | | | |
| | MW-29 | GW | | | X | | X | X | X | | | X | X | | | |
| | MW-53 | GW | | | X | | X | X | X | X | X | X | X | X | X | X |
| | MW-54 | GW | | | X | | X | X | X | X | X | X | X | X | X | X |
| | Vent Well | GW | | | X | | X | X | X | | | X | X | X | X | X |

Notes:

1. Field parameters consist of pH, temperature, turbidity, conductivity, and oxidation reduction potential.
2. Continuous lab or field measurements.
3. Samples will be filtered and method-required preservative will be added prior to analysis.
4. Total metals consist of: aluminum, arsenic, chromium, copper, iron, lead, manganese, and vanadium.
5. Dissolved metals consist of: aluminum, arsenic, chromium, copper, iron, lead, manganese, and vanadium.
6. Samples were initially analyzed for total carbon, and then the sample will be purged and measured for total organic carbon, giving the total inorganic carbon result by subtraction.
7. Anions consist of chloride, sulfate, and phosphate.
8. Cations consist of sodium, calcium, potassium, magnesium, aluminum, and iron.
9. No headspace.
10. Monitored until levels reach a steady state.

Abbreviations:

-- = not applicable
°C = degrees Celsius
$CaCO_3$ = calcium carbonate
EPA = Environmental Protection Agency
GW = groundwater
HDPE = high-density polyethylene
$HNO_3$ = nitric acid
L = liter
mg/L = milligrams per liter
N = normal
NaOH = sodium hydroxide
SM = Standard Method

**TABLE 7: SUMMARY OF PHASE 1 INJECTION EVENTS**

Former Rhone-Poulenc Site, Tukwila, Washington

| Injection Event Number | Injection Pressure[1] (psig) | Start Time | Stop Time | Duration (hours) | $CO_2$ Injected[2] (SCF) | Average Flow Rate[3] (SCFM) | $CO_2$ Injected (lbs) | Notes |
|---|---|---|---|---|---|---|---|---|
| 1 | 18 | 4/10/2018 9:05 | 4/10/2018 15:40 | 6.6 | 1,713 | 4.3 | 196 | Flow rate was zero SCFM until 9:11 as injection well groundwater was displaced. |
| 2 | 20 | 4/16/2018 8:52 | 4/16/2018 15:30 | 6.6 | 4,797 | 12.1 | 549 | Flow exceeded flow meter's maximum of 20 SCFM for last 2 hours of injection event. |
| 3 | 23 | 4/20/2018 8:28 | 4/20/2018 15:20 | 6.9 | 6,396 | 15.5 | 732 | Flow did not exceed flow meter's maximum of 20 SCFM. |
| 4 | 26 | 4/27/2018 8:22 | 4/27/2018 15:26 | 7.1 | 8,394 | 19.8 | 960 | Flow exceeded flow meter's maximum of 20 SCFM at 11:37 AM. |
| 5 | 28 | 5/2/2018 8:25 | 5/2/2018 15:20 | 6.9 | 10,679 | 25.7 | 1,222 | Flow exceeded flow meter's maximum of 20 SCFM at 8:58 AM. |

Notes

1. Injection pressure is based on manual readings of the injection wellhead manifold pressure gauge (PI-4). 
2. The total quantity of $CO_2$ injected was calculated by using changes in $CO_2$ tank level.
3. The average flow rate was determined using the total $CO_2$ injected divided by the injection event duration.

Abbreviations

lbs = pounds

psig = pounds per square inch gauge

SCF = standard cubic feet

SCFM = standard cubic feet per minute

**TABLE 8: SUMMARY OF PHASE 2 GROUNDWATER MONITORING[1]**

Former Rhone-Poulenc Site, Tukwila, Washington

| Well ID | Phase II Initial pH[2] (SU) | Phase II Final pH (SU) | Date pH / Water Level Transducer Removed | Notes |
|---|---|---|---|---|
| MW-53 | 6.6 | 6.8 | July 13, 2018 | The battery in this transducer failed; therefore, no data were collected from May 17 to May 18, 2018. |
| MW-54 | 7.3 | 8.2 | July 13, 2018 | The battery in this transducer failed; therefore, no data were collected from May 7 to May 18, 2018. |
| IMW-A1-D | 9.8 | 9.4 | July 13, 2018 | NA |
| IMW-A2-D | 9.7 | 10.5 | July 13, 2018 | An unknown sensor error occurred; therefore, no data were collected from May 8 to May 9, 2018. |
| IMW-B1-D | 11.6 | 11.5 | May 18, 2018 | Water level, pH, and temperature were monitored by collecting weekly grab samples from May 18 to July 13, 2018. |
| Injection Well | NM | 7.1 | July 13, 2018 | Transducer was added on May 18, 2020. An unknown sensor error occurred; therefore, no data were collected from June 25 to June 28, 2018. |
| IMW-A2-S | 6.9 | 6.4 | July 13, 2018 | The battery in this transducer failed; therefore, no data were collected from May 18 to May 26, 2018. After batteries were restored on May 26, the pH recorded by the transducer was 6.7 SU and increased steadily at a rate of 0.5 SU per week. On June 26, 2018, the transducer was calibrated, and the pH was measured to be approximately 6.7 SU; the increase in pH observed during June 2018 was attributed to calibration drift by the pH sensor. |
| IMW-B1-S | 8.5 | 7.7 | July 13, 2018 | The pH appeared to fluctuate tidally around 7.7 SU, but the pH briefly increased to approximately 9.0 SU twice during high tide events. |
| IMW-B2-S | 7.2 | 7.7 | May 18, 2018 | Water level, pH, and temperature were monitored by collecting weekly grab samples from May 18 to July 13, 2018. |
| IMW-C1-S | 7.1 | 7.1 | May 18, 2018 | Water level, pH, and temperature were monitored by collecting weekly grab samples from May 18 to July 13, 2018. |
| Vent Well | 7.5 | 7.5 | May 18, 2018 | Water level, pH, and temperature were monitored by collecting weekly grab samples from May 18 to July 13, 2018. |
| MW-29 | 7.1 | 7.1 | May 18, 2018 | Water level, pH, and temperature were monitored by collecting weekly grab samples from May 18 to July 13, 2018. |

Notes

1. Phase 2 groundwater monitoring began in all wells on May 3, 2020.
2. Phase 2 Initial pH is value recorded 24 hours after Phase 1 injection event 5.

Abbreviations

NM = not measured

SU = standard pH units

**TABLE 9: SUMMARY OF PHASE 3 INJECTION EVENTS**

Former Rhone-Poulenc Site, Tukwila, Washington

| Injection Number | Number of Cycles | Start Time | Stop Time | Injection Duration (hours) | $CO_2$ Injected[1] (SCF) | $CO_2$ Injected[1] (Pounds) | Average Flow Rate[2] (SCFM) | Initial Injection Pressure[3] (psi) | Final Injection Pressure[3] (psi) | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 11/12/2018 9:30 | 11/12/2018 17:30 | 6.0 | 7,083 | 810 | 19.7 | 29.5 | 22.0 | None |
| 2 | 3 | 11/13/2018 8:00 | 11/13/2018 16:00 | 6.0 | 7,169 | 820 | 19.9 | 26.0 | 22.0 | None |
| 3 | 3 | 11/14/2018 7:45 | 11/14/2018 15:45 | 6.0 | 7,101 | 812 | 19.7 | 25.0 | 22.0 | MW-53 wellhead pressure was 7.5 psig during injection and 3.5 psig during rebound. Wellhead pressure in all monitoring wells remained less than 1.0 psig. |
| 4 | 3 | 11/15/2018 8:00 | 11/15/2018 16:00 | 6.0 | 7,103 | 813 | 19.7 | 25.0 | 22.0 | MW-53 wellhead pressure was 7.7 psig during injection and had sulfur smell. Wellhead pressure in all monitoring wells remained less than 1.0 psig. |
| 5 | 3 | 11/16/2018 8:00 | 11/16/2018 16:00 | 6.0 | 7,108 | 813 | 19.7 | 25.0 | 22.0 | MW-53 wellhead pressure was 7.7 psig during injection and maximum hydrogen sulfide concentration was 25 to 30 ppm. Wellhead pressure in all monitoring wells remained less than 1.0 psig. |
| 6 | 3 | 11/19/2018 9:00 | 11/19/2018 17:00 | 6.0 | 7,161 | 819 | 19.9 | 27.0 | 22.0 | MW-53 wellhead pressure was 7.7 psig during injection and maximum hydrogen sulfide concentration was 25 to 30 ppm. Wellhead pressure in all monitoring wells remained less than 1.0 psig. |
| 7 | 3 | 11/20/2018 8:40 | 11/20/2018 16:40 | 6.0 | 7,196 | 823 | 20.0 | 24.0 | 20.0 | MW-53 wellhead pressure was 7.7 psig during injection and maximum hydrogen sulfide concentration was 33 to 65 ppm. Wellhead pressure in all monitoring wells remained less than 1.0 psig. |
| 8 | 3 | 11/21/2018 8:00 | 11/21/2018 16:00 | 6.0 | 7,153 | 818 | 19.9 | 22.0 | 20.0 | MW-53 wellhead pressure was 8.0 psig during injection and maximum hydrogen sulfide concentration was 19 to 69 ppm. Wellhead pressure in all monitoring wells remained less than 1.0 psig. |
| 9 | 3 | 11/27/2018 8:00 | 11/27/2018 16:00 | 6.0 | 7,157 | 819 | 19.9 | 27.0 | 22.0 | MW-53 wellhead pressure was 7.8 psig during injection and maximum hydrogen sulfide concentration was 27 to 70 ppm. Wellhead pressure in all monitoring wells remained less than 1.0 psig. |
| 10 | 3 | 11/28/2018 8:00 | 11/28/2018 16:00 | 6.0 | 7,154 | 818 | 19.9 | 22.0 | 20.0 | MW-53 wellhead pressure was 7.9 psig during injection and maximum hydrogen sulfide concentration was 23 to 68 ppm. Wellhead pressure in all monitoring wells remained less than 1.0 psig. |
| 11 | 3 | 11/29/2018 8:00 | 11/29/2018 16:00 | 6.0 | 6,185 | 708 | 17.2 | 22.0 | 16.0 | Ran out of $CO_2$ during third cycle. MW-53 wellhead pressure was 8.1 psig during injection and maximum hydrogen sulfide concentration was similar to previous injection events. Wellhead pressure in all monitoring wells remained less than 1.0 psig. |
| 12 | 2 | 12/5/2018 11:25 | 12/5/2018 16:25 | 4.0 | 4,749 | 543 | 19.8 | 26.0 | 22.0 | IMW-A1-D, IMW-B1-D, and IMW-A2-D were purged for approximately 30 minutes each on 11/30/2018. Only two injection cycles were completed due to time required to fill the bulk $CO_2$ tanks. MW-53 observations were similar to previous injection events. |
| 13 | 2 | 12/6/2018 11:35 | 12/6/2018 16:35 | 4.0 | 4,789 | 548 | 20.0 | 24.0 | 22.0 | Only two injection cycles were completed due to low temperatures. MW-53 observations were similar to previous injection events. |
| 14 | 3 | 12/7/2018 9:20 | 12/7/2018 17:20 | 6.0 | 7,107 | 813 | 19.7 | 23.0 | 20.5 | MW-53 observations were similar to previous injection events. |
| 15 | 3 | 12/10/2018 7:55 | 12/10/2018 15:55 | 6.0 | 7,144 | 817 | 19.8 | 25.5 | 20.0 | MW-53 observations were similar to previous injection events. |
| 16 | 3 | 12/11/2018 8:00 | 12/11/2018 16:00 | 6.0 | 7,048 | 806 | 19.6 | 22.0 | 20.0 | MW-53 observations were similar to previous injection events. |
| 17 | 3 | 12/12/2018 7:30 | 12/12/2018 15:30 | 6.0 | 7,114 | 814 | 19.8 | 21.0 | 19.5 | MW-53 observations were similar to previous injection events. |
| 18 | 3 | 12/13/2018 7:45 | 12/13/2018 15:45 | 6.0 | 7,066 | 808 | 19.6 | 21.0 | 20.0 | MW-53 observations were similar to previous injection events. |
| 19 | 3 | 12/14/2018 7:45 | 12/14/2018 15:45 | 6.0 | 7,071 | 809 | 19.6 | 20.5 | 19.5 | MW-53 observations were similar to previous injection events. |
| 20 | 3 | 12/20/2018 8:10 | 12/20/2018 16:10 | 6.0 | 7,115 | 814 | 19.8 | 26.5 | 21.0 | MW-53 observations were similar to previous injection events. |
| 21 | 3 | 12/21/2018 8:00 | 12/21/2018 16:00 | 6.0 | 7,080 | 810 | 19.7 | 22.0 | 20.0 | MW-53 observations were similar to previous injection events. |

Notes

1. The total quantity of $CO_2$ injected was calculated by using changes in $CO_2$ tank level.
2. The average flow rate was determined using the total $CO_2$ injected divided by the injection event duration.
3. Injection pressure is based on manual readings of the injection wellhead manifold pressure gauge (PI-4).

Abbreviations

lbs = pounds

ppm = parts per million

psig = pounds per square inch gauge

SCF = standard cubic feet

SCFM = standard cubic feet per minute

**TABLE 10: SUMMARY OF PHASE 4 GROUNDWATER MONITORING[1]**

Former Rhone-Poulenc Site, Tukwila, Washington

| Well ID | Phase 4 Initial pH[2] (SU) | Phase 4 Final pH[3] (SU) | Date pH / Water Level Transducer Removed | Notes |
|---|---|---|---|---|
| MW-53 | 6.2 | 5.8 | February 7, 2019 | NA |
| MW-54 | 6.8 | 7.6 | NA | MW-54 was not monitored during Phase 4 testing. |
| IMW-A1-D | 8.1 | 8.1 | February 28, 2019 | NA |
| IMW-A2-D | 7.5 | 7.0 | February 28, 2019 | NA |
| IMW-B1-D | 11.7 | 11.5 | February 7, 2019 | NA |
| Injection Well | 7.1 | 7.0 | February 18, 2019 | Transducer was added on January 11, 2019. |
| IMW-A2-S | 6.1 | 6.4 | February 1, 2019 | NA |
| IMW-B1-S | 7.4 | 6.3 | February 28, 2019 | Transducer replaced on February 18, 2019. |
| IMW-B2-S | 6.7 | 6.5 | NA | IMW-B2-S was not monitored during Phase 4 testing. |
| IMW-C1-S | 6.8 | 6.5 | NA | IMW-C1-S was not monitored during Phase 4 testing. |
| Vent Well | 6.8 | 6.8 | NA | Vent Well was not monitored during Phase 4 testing. |
| MW-29 | 6.4 | 6.5 | NA | MW-29 was not monitored during Phase 4 testing. |

Notes

1. Phase 4 groundwater monitoring began on December 26, 2018.
2. Phase 4 Initial pH is the value recorded 24 hours after final Phase 3 injection event or the value recorded during post Phase 3 groundwater sampling.
3. Phase 4 Final pH is the value recorded during post Phase 4 groundwater sampling.

Abbreviations

NA = not applicable

SU = standard pH units

**TABLE 11: PILOT STUDY ANALYTICAL DATA FOR CONVENTIONAL WATER QUALITY PARAMETERS[1]**

Former Rhone-Poulenc Site, Tukwila, Washington

| Analysis | Well ID | Phase 1 | | | | | | Phase 2 | Phase 3 | Phase 4 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pre-injection | Post Injection 1 | Post Injection 2 | Post Injection 3 | Post Injection 4 | Post Injection 5 | Post Rebound | Post Injection | Post Rebound |
| Alkalinity SM 2320 B-97 (mg $CaCO_3$/L) | MW-53 | 2,520 | 2,040 | 2,120 | 2,370 | 2,310 | 2,200 | 2,010 | 1,350 | 1,990 |
| | MW-54 | 36.6 | 430 | 715 | 965 | 1,070 | 1,250 | 623 | 1,170 | 856 |
| | Injection Well | 10,500 | NM | NM | NM | NM | 16,700 | 17,400 | 18,700 | 17,900 |
| | IMW-A2-S | 728 | 613 | 635 | 670 | 700 | 732 | 927 | 1,150 | 1,030 |
| | IMW-A2-D | 6,530 | 6,680 | 6,800 | 6,690 | 9,500 | 12,200 | 11,800 | 13,600 | 10,000 |
| | IMW-B2-S | 397 | 419 | 393 | 401 | 366 | 420 | 462 | 496 | 547 |
| | IMW-A1-D | 12,100 | 12,400 | 11,900 | 12,300 | 12,900 | 12,100 | 317 | 9,290 | 689 |
| | Vent Well | 502 | 544 | 502 | 510 | 485 | 534 | 623 | 658 | 702 |
| | IMW-B1-S | 1,030 | 943 | 903 | 919 | 923 | 957 | 988 | 1,080 | 1,080 |
| | IMW-B1-D | 12,400 | 13,700 | 11,700 | 13,500 | 13,900 | 14,400 | 4,790 | 11,400 | 6,400 |
| | IMW-C1-S | 724 | 706 | 674 | 672 | 654 | 697 | 746 | 828 | 888 |
| | MW-29 | 509 | 530 | 513 | 528 | 504 | 540 | 549 | 524 | 506 |
| Dissolved Silica EPA 6020 (mg/L) | MW-53 | 326 | 230 | 189 | 106 | 83.7 | 76.2 | 56.3 | 47.6 | 51.1 |
| | MW-54 | 2.56 | 30.0 | 87.5 | 88.7 | 61.1 | 73.8 | 31.1 | 55.5 | 41.0 |
| | Injection Well | 4,530 | NM | NM | NM | NM | 53.3 | 67.8 | 49.5 | 46.5 |
| | IMW-A2-S | 39.1 | 36.6 | 37.9 | 39.7 | 39.2 | 45.4 | 33.6 | 47.1 | 43.2 |
| | IMW-A2-D | 1,400 | 1,890 | 2,440 | 1,530 | 2,760 | 915 | 48.9 | 48.1 | 46.8 |
| | IMW-B2-S | 39.1 | 39.6 | 38.9 | 38.9 | 36.3 | 40.6 | 32.1 | 45 | 40.1 |
| | IMW-A1-D | 5,210 | 601 | 618 | 5,370 | 4,110 | 1,520 | 36.4 | 62 | 48.3 |
| | Vent Well | 43.2 | 43.3 | 46.4 | 42.1 | 39.5 | 44.0 | 41.4 | 44.6 | 43.4 |
| | IMW-B1-S | 49.5 | 43.1 | 44.3 | 45.9 | 46.8 | 48.8 | 42.9 | 58 | 46.7 |
| | IMW-B1-D | 5,830 | 714 | 626 | 6,730 | 6,230 | 6,760 | 2,180 | 1,820 | 68.2 |
| | IMW-C1-S | 45.6 | 48.2 | 46.5 | 46.2 | 43.0 | 46.9 | 38.5 | 48.5 | 48.0 |
| | MW-29 | 43.6 | 45.4 | 44.2 | 43 | 42.9 | 44.3 | 38.8 | 46.7 | 37.4 |
| Dissolved Total Inorganic Carbon SM 5310 B-00 (mg/L) | MW-53 | 247.8 | 229.0 | 315.6 | 564.9 | 681.4 | 747.2 | 564.2 | 504.5 | 620.2 |
| | MW-54 | 14.89 | 96.65 | 129.9 | 194.4 | 243.9 | 327.3 | 137.2 | 313.6 | 190.7 |
| | Injection Well | 355.2 | NM | NM | NM | NM | 3,914 | 4,491 | 4,443 | 4,732 |
| | IMW-A2-S | 185.7 | 156.9 | 161 | 171.4 | 189.4 | 242.1 | 242.5 | 317.5 | 427.3 |
| | IMW-A2-D | 395.2 | 396.1 | 401.6 | 418.9 | 630.6 | 1,849 | 2,422 | 3,304 | 2,167 |
| | IMW-B2-S | 119.3 | 97.30 | 104.3 | 93.59 | 112.2 | 136.8 | 114.5 | 148.7 | 170.0 |
| | IMW-A1-D | 432 | 421.9 | 481.1 | 491.6 | 822.5 | 1,259 | 617 | 2,098 | 1,474 |
| | Vent Well | 141.7 | 139.1 | 135.1 | 129.5 | 139.9 | 159.6 | 152.7 | 184.5 | 219.2 |
| | IMW-B1-S | 249.7 | 233.1 | 241.0 | 210.3 | 222.3 | 246.6 | 223.3 | 267.1 | 287.0 |
| | IMW-B1-D | 443.0 | 414.9 | 476.7 | 488.8 | 469.8 | 425.0 | 264.1 | 1,139 | 1,159 |
| | IMW-C1-S | 203.2 | 183.7 | 185.4 | 183.0 | 189.2 | 207.8 | 188.8 | 218.8 | 270.9 |
| | MW-29 | 152.6 | 140.3 | 138.1 | 137.3 | 151.2 | 181.6 | 142.6 | 160.1 | 163.5 |

## TABLE 11: PILOT STUDY ANALYTICAL DATA FOR CONVENTIONAL WATER QUALITY PARAMETERS[1]

Former Rhone-Poulenc Site, Tukwila, Washington

| Analysis | Well ID | Phase 1 | | | | | | Phase 2 | Phase 3 | Phase 4 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pre-injection | Post Injection 1 | Post Injection 2 | Post Injection 3 | Post Injection 4 | Post Injection 5 | Post Rebound | Post Injection | Post Rebound |
| Sulfide SM 4500 S2 D-00 (mg/L) | MW-53 | 45.2 | NM | NM | NM | NM | 0.108 | 0.050 U | 0.170 | 0.050 U |
| | MW-54 | 0.050 U | NM | NM | NM | NM | 0.050 U | 0.050 U | 0.119 | 0.050 U |
| | Injection Well | 142 | NM | NM | NM | NM | 0.050 U | 0.050 U | 0.050 U | 0.050 U |
| | IMW-A2-S | 0.050 U | NM | NM | NM | NM | NM | NM | NM | NM |
| | IMW-A2-D | 105 | NM | NM | NM | NM | NM | NM | NM | NM |
| | IMW-B2-S | 0.037 | NM | NM | NM | NM | NM | NM | NM | NM |
| | IMW-A1-D | 112 | NM | NM | NM | NM | 23.0 | 1.7 | 14.6 | 18.7 |
| | Vent Well | 0.05 U | NM | NM | NM | NM | 0.060 H | 0.05 U | 0.05 U | 0.050 U |
| | IMW-B1-S | NM | NM | NM | NM | NM | NM | NM | NM | NM |
| | IMW-B1-D | NM | NM | NM | NM | NM | NM | NM | NM | NM |
| | IMW-C1-S | NM | NM | NM | NM | NM | NM | NM | NM | NM |
| | MW-29 | NM | NM | NM | NM | NM | NM | NM | NM | NM |
| Total Dissolved Solids SM 2540 C-97 (mg/L) | MW-53 | 6,460 | 4,720 | 3,820 | 4,910 | 3,530 | 2,920 | 12,400 | 1,860 | 2,280 |
| | MW-54 | 66 | 968 | 1,630 | 1,580 | 2,120 | 2,160 | 1,430 | 2,090 | 3,830 |
| | Injection Well | 20,500 | NM | NM | NM | NM | 19,600 | 20,200 | 19,700 | 19,300 |
| | IMW-A2-S | 1,060 | 869 | 897 | 847 | 971 | 907 | 1,170 | 1,260 | 1,130 |
| | IMW-A2-D | 13,400 | 14,200 | 14,700 | 13,300 | 20,400 | 12,300 | 15,800 | 16,600 | 11,700 |
| | IMW-B2-S | 457 | 502 | 498 | 528 | 513 | 506 | 524 | 641 | 619 |
| | IMW-A1-D | 25,300 | 26,900 | 26,000 | 24,700 | 26,400 | 15,900 | 522 | 12,800 | 1,980 |
| | Vent Well | 582 | 641 | 637 | 652 | 633 | 595 | 765 | 824 | 842 |
| | IMW-B1-S | 1,260 | 1,080 | 1,070 | 1,100 | 1,070 | 1,120 | 1,210 | 1,290 | 1,210 |
| | IMW-B1-D | 28,400 | 32,000 | 26,800 | 28,100 | 32,600 | 29,200 | 14,100 | 21,400 | 16,800 |
| | IMW-C1-S | 793 | 817 | 825 | 848 | 780 | 808 | 887 | 964 | 1,020 |
| | MW-29 | 624 | 655 | 642 | 673 | 511 | 617 | 628 | 698 | 639 |
| Total Suspended Solids SM 2540 D-97 (mg/L) | MW-53 | 1 | NM | NM | NM | NM | 2 | 13 | 31 | 77 |
| | MW-54 | 11 | NM | NM | NM | NM | 13 | 6 | 1 | 4 |
| | Injection Well | 25 | NM | NM | NM | NM | 37 | 17 | 22 | 29 |
| | IMW-A2-S | 18 | NM | NM | NM | NM | 52 | 24 | 50 | 71 |
| | IMW-A2-D | 57 | NM | NM | NM | NM | 5,660 | 404 | 38 | 12 |
| | IMW-B2-S | 91 | NM | NM | NM | NM | 102 | 50 | 83 | 80 |
| | IMW-A1-D | 37 | NM | NM | NM | NM | 591 | 42 | 16 | 11 |
| | Vent Well | 23 | NM | NM | NM | NM | 66 | 17 | 2 | 20 |
| | IMW-B1-S | 6 | NM | NM | NM | NM | 1 U | 2 | 1 U | 42 |
| | IMW-B1-D | 79 | NM | NM | NM | NM | 4 | 17 | 126 | 222 |
| | IMW-C1-S | 29 | NM | NM | NM | NM | 77 | 52 | 38 | 58 |
| | MW-29 | 122 | NM | NM | NM | NM | 100 | 53 | 38 | 56 |

Notes

1. Data qualifiers are as follows:
   U = Analyte not detected at or above the reporting limit indicated.
   H = Hold time was exceeded.

Abbreviations

EPA = United States Environmental Protection Agency
mg $CaCO_3$/L = milligrams calcium carbonate per liter
mg/L = milligrams per liter
NM = not measured
SM = Standard Method

# TABLE 12: PILOT STUDY ION DATA[1]

Former Rhone-Poulenc Site, Tukwila, Washington

| Analysis | | Well ID | Pre Phase 1 | Post Phase 1 | Post Phase 2 | Post Phase 3 | Post Phase 4 |
|---|---|---|---|---|---|---|---|
| Anions | Chloride EPA 300.0 (mg/L) | MW-53 | 1,980 | 217 | 300 | 17.5 | 106 |
| | | MW-54 | 1.80 | 311 | 494 | 348 | 326 |
| | | Injection Well | 352 | 1,020 | 657 | 651 | 619 |
| | | IMW A1-D | 353 | 232 | 372 | 1,080 | 49.7 |
| | | Vent Well | 3.53 | 3.58 | 4.03 | 5.35 | 5.63 |
| | Phosphate EPA 300.0 (mg-P/L) | MW-53 | 7.54 | 3.22 | 17.4 H | 0.50 U | 1.00 YI, U |
| | | MW-54 | 0.10 U | 18.9 | 4.22 H | 21.4 | 28.9 H |
| | | Injection Well | 43.7 | 27.4 | 21.1 H | 18.4 | 6.81 YI |
| | | IMW A1-D | 48.1 | 31.3 | 13.0 H | 26 | 3.75 YI |
| | | Vent Well | 0.10 U | 0.10 U | 0.50 H, YI, U | 0.10 H, U | 0.10 U |
| | Sulfate EPA 300.0 (mg/L) | MW-53 | 7.22 | 0.648 | 0.500 YI, U | 0.513 | 12.1 |
| | | MW-54 | 3.00 | 0.911 | 0.500 U | 2.00 U | 0.100 U |
| | | Injection Well | 37.4 | 27.9 | 30.6 | 27.8 | 22.8 |
| | | IMW A1-D | 23.0 | 15.3 | 8.66 | 5.00 U | 0.200 YI, U |
| | | Vent Well | 0.500 U | 0.290 | 0.500 YI, U | 0.235 | 0.963 |
| Cations | Aluminum EPA 6010C (mg/L) | MW-53 | 1.04 | 25.0 U | 1.13 | 0.252 J | 0.302 |
| | | MW-54 | 0.143 | 0.456 J | 0.696 | 1.22 | 2.00 |
| | | Injection Well | 7.03 | 2.50 U | 0.151 J, D | 5.00 U | 0.0524 J |
| | | IMW A1-D | 10.1 | 25.0 U | 0.134 J, D | 0.423 J | 0.157 |
| | | Vent Well | 0.0973 | 1.00 U | 0.0493 J | 0.420 J | 0.0932 |
| | Calcium EPA 6010C (mg/L) | MW-53 | 14.3 | 45.7 | 64.5 | 95.9 | 75.0 |
| | | MW-54 | 9.94 | 12.9 | 7.58 | 13.2 | 9.08 |
| | | Injection Well | 16.2 | 136 | 167 | 143 | 141 |
| | | IMW A1-D | 24.8 | 22.5 J | 17.8 | 18.1 | 12.7 |
| | | Vent Well | 45.6 | 33.8 | 31.3 | 32.4 | 34.8 |
| | Iron EPA 6010C (mg/L) | MW-53 | 7.45 | 25.4 | 54.1 | 91.4 | 87.2 |
| | | MW-54 | 0.332 | 0.764 J | 1.32 | 12.9 | 7.01 |
| | | Injection Well | 17.5 | 26.1 | 33.2 | 38.4 | 40.4 |
| | | IMW A1-D | 22.8 | 2.61 J | 2.02 | 5.29 | 0.810 |
| | | Vent Well | 36.2 | 26.1 | 20.5 | 23.1 | 24.9 |
| | Magnesium EPA 6010C (mg/L) | MW-53 | 0.680 | 16.1 | 22.5 | 29.9 | 28.6 |
| | | MW-54 | 0.463 | 6.94 | 4.43 | 11.4 | 6.75 |
| | | Injection Well | 2.48 J | 64.5 | 116 | 121 | 115 |
| | | IMW A1-D | 1.99 J | 25.0 U | 0.877 | 2.20 | 1.14 |
| | | Vent Well | 16.1 | 13.5 | 13.4 | 14 | 15.2 |
| | Potassium EPA 6010C (mg/L) | MW-53 | 43.7 | 25.6 | 18.7 | 17.9 | 38.0 |
| | | MW-54 | 0.435 J | 23.0 | 17.6 | 27.5 | 21.1 |
| | | Injection Well | 68.0 | 155 J | 205.0 | 192 | 188 |
| | | IMW A1-D | 68.4 | 72.1 J | 34.8 | 50.7 | 7.55 |
| | | Vent Well | 8.67 | 6.53 | 6.88 | 8.16 J | 6.84 |
| | Sodium EPA 6010C (mg/L) | MW-53 | 2,300 | 1,040 | 1,270 | 717 | 905 |
| | | MW-54 | 3.02 | 756 | 508 | 764 | 641 |
| | | Injection Well | 5,140 | 7,910 | 8,870 | 7,440 | 7670 |
| | | IMW A1-D | 5,950 | 5,990 | 2,260 | 4,190 | 316 |
| | | Vent Well | 152 | 172 | 247 | 253 | 262 |

Notes

1. Data qualifiers are as follows:
   - D = The reported value is from a dilution.
   - J = The result is an approximation.
   - U = Analyte not detected at or above the reporting limit indicated.
   - H = Hold time was exceeded.
   - YI = Raised reporting limit due to interference.

Abbreviations

EPA = United States Environmental Protection Agency
mg/L = milligram per liter
mg-P/L = milligrams phosphorous per liter

## TABLE 13: PILOT STUDY METALS DATA[1]

Former Rhone-Poulenc Site, Tukwila, Washington

Results reported in micrograms per liter (µg/L)

| Analysis | | Well Location | Pre Phase 1 | Post Phase 3 | Post Phase 4 |
|---|---|---|---|---|---|
| Dissolved Metals | Aluminum EPA 6020A | MW-53 | 1,030 | 56.8 J | 79.0 J |
| | | MW-54 | 41.5 | 639 | 766 |
| | | Injection Well | 5,700 | 2,000 U | 33.4 J |
| | | IMW-A1-D | 9,080 | 5,000 U | 88.4 J |
| | Arsenic EPA 6020A UCT-KED | MW-53 | 24.5 | 2.42 J | 7.03 |
| | | MW-54 | 0.298 | 2.76 J | 3.29 |
| | | Injection Well | 104 | 5.90 J | 3.65 |
| | | IMW-A1-D | 93.4 | 24.5 J | 15.2 |
| | Chromium EPA 6020A | MW-53 | 132 | 8.84 J | 8.47 |
| | | MW-54 | 0.564 | 12.6 | 10.4 |
| | | Injection Well | 318 | 83.9 | 64.6 |
| | | IMW-A1-D | 683 | 393 | 206 |
| | Copper EPA 6020A UCT-KED | MW-53 | 268 | 10.0 U | 2.34 |
| | | MW-54 | 0.926 | 9.88 J | 13.3 |
| | | Injection Well | 61.5 | 50.0 U | 13.9 |
| | | IMW-A1-D | 136 | 125 U | 25.6 |
| | Iron EPA 6020A | MW-53 | 6,590 | 91,000 | 79,400 |
| | | MW-54 | 140 | 12500 | 4,700 |
| | | Injection Well | 11,300 | 46,200 | 40,300 |
| | | IMW-A1-D | 17,300 | 3,790 J | 2,120 |
| | Lead EPA 6020A | MW-53 | 25.8 | 5.00 U | 0.158 J |
| | | MW-54 | 0.133 | 2.00 U | 0.562 |
| | | Injection Well | 2.38 J | 10.0 U | 1.00 U |
| | | IMW-A1-D | 3.85 | 25.0 U | 2.16 |
| | Manganese EPA 6020A | MW-53 | 164 | 8610 | 6,120 |
| | | MW-54 | 24.6 | 744 | 320 |
| | | Injection Well | 53.0 | 2,030 | 1,620 |
| | | IMW-A1-D | 74.9 | 35.0 J | 38.6 |
| | Vanadium EPA 6020A | MW-53 | 650 | 31.2 | 31.3 |
| | | MW-54 | 2.17 | 47.7 | 51.3 |
| | | Injection Well | 2,200 | 281 | 291 |
| | | IMW-A1-D | 3,810 | 1,370 | 741 |

## TABLE 13: PILOT STUDY METALS DATA[1]

Former Rhone-Poulenc Site, Tukwila, Washington

Results reported in micrograms per liter (µg/L)

| Analysis | | Well Location | Pre Phase 1 | Post Phase 3 | Post Phase 4 |
|---|---|---|---|---|---|
| Total Metals | Aluminum EPA 6020A | MW-53 | 1,040 | 2,520 J | 246 |
| | | MW-54 | 90.0 | 1,220 | 1510 |
| | | Injection Well | 7,120 | 850 U | 54.6 J |
| | | IMW-A1-D | 9,970 | 423 J | 2,200 |
| | Arsenic EPA 6020A UCT-KED | MW-53 | 22.8 | 2.80 J | 8.54 |
| | | MW-54 | 0.187 J | 3.76 J | 4.83 |
| | | Injection Well | 105 | 4.70 J | 5.07 |
| | | IMW-A1-D | 96.8 | 39.8 J | 3.21 |
| | Chromium EPA 6020A | MW-53 | 130 | 6.22 J | 17.7 |
| | | MW-54 | 0.405 J | 15.1 | 12.9 |
| | | Injection Well | 327 | 78 | 84.3 |
| | | IMW-A1-D | 675 | 540 | 32.9 |
| | Copper EPA 6020A UCT-KED | MW-53 | 286 | 10.0 U | 6.61 |
| | | MW-54 | 2.93 | 12.1 | 15.4 |
| | | Injection Well | 73.0 | 50.0 U | 9.15 |
| | | IMW-A1-D | 152 | 125 U | 20.7 |
| | Iron EPA 6020A | MW-53 | 6,450 | 91,400 | 77,100 |
| | | MW-54 | 263 | 12900 | 5,630 |
| | | Injection Well | 13,700 | 38,400 | 44,000 |
| | | IMW-A1-D | 18,000 | 5,290 | 741 |
| | Lead EPA 6020A | MW-53 | 25.8 | 2.00 U | 0.885 |
| | | MW-54 | 0.905 | 2.00 U | 1.08 |
| | | Injection Well | 3.80 | 10.0 U | 1.00 U |
| | | IMW-A1-D | 4.80 | 25.0 U | 4.44 |
| | Manganese EPA 6020A | MW-53 | 155 | 7,780 | 5,820 |
| | | MW-54 | 25.1 | 764 | 329 |
| | | Injection Well | 90.0 | 2,020 | 1,840 |
| | | IMW-A1-D | 90.8 | 27.8 J | 34.3 |
| | Vanadium EPA 6020A | MW-53 | 619 | 28.4 | 66.9 |
| | | MW-54 | 0.280 | 65.9 | 63.8 |
| | | Injection Well | 2,240 | 319 | 314 |
| | | IMW-A1-D | 4,120 | 2,140 | 128 |

Notes

1. Data qualifiers are as follows:
   J = The result is an approximation.
   U = Analyte not detected at or above the reporting limit.

Abbreviations

µg/L = micrograms per liter
EPA = United States Environmental Protection Agency
KED = kinetic energy discrimination
UCT = Universal Cell Technology™

**TABLE 14: GROUNDWATER CHEMISTRY BENCH STUDY**

Former Rhone-Poulenc Site, Tukwila, WA

| Analysis | Unit | Before Titration | After Titration |
|---|---|---|---|
| pH | SU | 11.62 | 6.49 |
| Silicon, Dissolved | mg/L | 4,540 | 56.0 |
| Alkalinity, Total | mg/L $CaCO_3$ | 10,740 | 11,000 |
| Alkalinity, Hydroxide | mg/L $CaCO_3$ | 6,172 | - |
| Alkalinity, Carbonate | mg/L $CaCO_3$ | 4,572 | - |
| Alkalinity, Bicarbonate | mg/L $CaCO_3$ | 1.000 | - |
| Total Suspended Solids | mg/L | 73 | 10,910 |
| Total Dissolved Solids | mg/L | 20,680 | - |

Abbreviations

mg = milligram

L = Liter

$CaCO_3$ = calcium carbonate

SU = standard pH units

## TABLE 15: SOIL BUFFERING CAPACITY RESULTS - STAGE 1A AND 1B[1, 2, 3]

Former Rhone-Poulenc Site, Tukwila, WA

| Sample ID | Mass Soil (g) | Acidity Added (meq) | Initial pH (after 1 h) | pH (t=4 day) | pH (t=5 days) | pH (t=6 days) | pH (t=11 days) | pH (t=18 days) |
|---|---|---|---|---|---|---|---|---|
| **POORLY GRADED SAND (SP)** | | | | | | | | |
| Blank | 4.98 | 0.0 | 10.10 | 9.89 | 9.76 | NM | 9.70 | 9.54 |
| 0.5x alkalinity | 5.03 | 0.5 | 2.60 | 2.75 | NM | 2.78 | 2.82 | NM |
| 1x alkalinity | 5.05 | 1.1 | 2.23 | 2.31 | NM | 2.31 | 2.37 | NM |
| 2x alkalinity | 5.03 | 2.1 | 1.92 | 1.94 | NM | 1.91 | 1.98 | NM |
| 3x alkalinity | 5.04 | 3.2 | 1.72 | 1.76 | NM | 1.72 | 1.73 | NM |
| 5x alkalinity | 4.92 | 5.4 | 1.67 | 1.86 | 1.91 | NM | 1.85 | 1.85 |
| 10x alkalinity | 4.96 | 10.7 | 1.39 | 1.51 | 1.57 | NM | NM | NM |
| 15x alkalinity | 4.99 | 16.1 | 1.21 | 1.30 | 1.40 | NM | NM | NM |
| 20x alkalinity | 4.97 | 21.5 | 1.11 | 1.21 | 1.28 | NM | NM | NM |
| 25x alkalinity | 5.00 | 26.8 | 1.03 | 1.16 | 1.19 | NM | NM | NM |
| **SILT AND SILTY SAND (ML-SM)** | | | | | | | | |
| Blank | 4.97 | 0.0 | 10.16 | 9.84 | 9.87 | NM | 9.63 | 9.65 |
| 0.5x alkalinity | 5.01 | 0.5 | 3.47 | 3.65 | NM | 3.76 | 3.69 | NM |
| 1x alkalinity | 5.01 | 1.1 | 2.50 | 2.66 | NM | 2.70 | 2.79 | NM |
| 2x alkalinity | 5.00 | 2.1 | 1.99 | 2.08 | NM | 2.08 | 2.12 | NM |
| 3x alkalinity | 5.03 | 3.2 | 1.78 | 1.87 | NM | 1.81 | 1.85 | NM |
| 5x alkalinity | 4.95 | 5.4 | 1.82 | 2.05 | 2.10 | NM | 2.12 | 2.18 |
| 10x alkalinity | 4.98 | 10.7 | 1.43 | 1.58 | 1.61 | NM | NM | NM |
| 15x alkalinity | 4.98 | 16.1 | 1.24 | 1.37 | 1.39 | NM | NM | NM |
| 20x alkalinity | 5.01 | 21.5 | 1.13 | 1.28 | 1.31 | NM | NM | NM |
| 25x alkalinity | 4.98 | 26.8 | 1.03 | 1.15 | 1.19 | NM | NM | NM |

Notes

1. The alkalinity of the injection well groundwater is 10,743 mg $CaCO_3$/L.
2. The total volume of each solution was 100 mL.
3. All pH measurements are in standard pH units

Abbreviations

$CaCO_3$ = calcium carbonate
g = grams
h = hours
L = liter
meq = milliequivalent
mg = milligrams
ml = milliliter
NM = not measured
t = time

## TABLE 16: BUFFERING CAPACITY - STAGE 2 DEIONIZED WATER RESULTS[1, 2, 3]

Former Rhone-Poulenc Site, Tukwila, WA

| Aliquot # | Mass Soil (g) | Acidity Added (meq) | Initial pH (after 1 h) | pH (t=4 days)[4] | pH (t=5 days) | Notes |
|---|---|---|---|---|---|---|
| **Poorly Graded Sand (SP)** | | | | | | |
| 1 | 5.04 | 0.00 | 9.65 | 9.92 | 9.96 | Deionized water added |
| 2 | 5.03 | 0.03 | 5.64 | NM | 9.18 | Deionized water added |
| 3 | 5.05 | 0.05 | 3.38 | NM | 7.12 | Deionized water added |
| 4 | 5.03 | 0.08 | 3.11 | NM | 6.04 | Deionized water added |
| 5 | 5.04 | 0.11 | 3.00 | 5.28 | 5.13 | Deionized water added |
| 6 | 5.03 | 0.13 | 2.87 | NM | 4.82 | Deionized water added |
| 7 | 5.04 | 0.16 | 2.76 | NM | 4.35 | Deionized water added |
| 8 | 5.04 | 0.19 | 2.65 | NM | 4.04 | Deionized water added |
| 9 | 5.05 | 0.22 | 2.61 | 3.73 | 3.67 | Deionized water added |
| 10 | 5.03 | 0.24 | 2.54 | NM | 3.52 | Deionized water added |
| 11 | 5.05 | 0.27 | 2.51 | NM | 3.41 | Deionized water added |
| 12 | 5.02 | 0.30 | 2.44 | NM | 3.34 | Deionized water added |
| 13 | 5.06 | 0.33 | 2.35 | 3.20 | 3.23 | Deionized water added |
| 14 | 5.05 | 0.35 | 2.38 | NM | 3.17 | Deionized water added |
| 15 | 5.03 | 0.38 | 2.40 | NM | 3.16 | Deionized water added |
| 16 | 5.02 | 0.40 | 2.37 | NM | 3.09 | Deionized water added |
| 17 | 5.05 | 0.43 | 2.30 | 2.99 | 3.01 | Deionized water added |
| 18 | 5.06 | 0.46 | 2.29 | NM | 2.96 | Deionized water added |
| 19 | 5.08 | 0.49 | 2.26 | NM | 2.88 | Deionized water added |
| 20 | 5.07 | 0.52 | 2.21 | NM | 2.82 | Deionized water added |
| 21 | 5.06 | 0.54 | 2.26 | NM | 2.78 | Deionized water added |
| 22 | 5.04 | 0.00 | 9.79 | NM | 9.82 | Duplicate of Aliquot #1 |
| 23 | 5.05 | 0.05 | 3.44 | NM | 7.81 | Duplicate of Aliquot #3 |
| 24 | 5.07 | 0.16 | 2.73 | NM | 4.31 | Duplicate of Aliquot #7 |
| 25 | 5.03 | 0.27 | 2.48 | NM | 3.38 | Duplicate of Aliquot #11 |
| 26 | 5.05 | 0.38 | 2.37 | NM | 3.05 | Duplicate of Aliquot #15 |
| 27 | 5.03 | 0.49 | 2.27 | NM | 2.81 | Duplicate of Aliquot #19 |
| 28 | 5.04 | 0.54 | 2.22 | NM | 2.71 | Duplicate of Aliquot #21 |

## TABLE 16: BUFFERING CAPACITY - STAGE 2 DEIONIZED WATER RESULTS[1, 2, 3]

Former Rhone-Poulenc Site, Tukwila, WA

| Aliquot # | Mass Soil (g) | Acidity Added (meq) | Initial pH (after 1 h) | pH (t=4 days)[4] | pH (t=5 days) | Notes |
|---|---|---|---|---|---|---|
| **Silty and Silty Sand (ML-SM)** | | | | | | |
| 1 | 5.02 | 0.00 | 10.35 | 10.14 | 9.93 | Deionized water added |
| 2 | 4.96 | 0.03 | 10.03 | NM | 9.73 | Deionized water added |
| 3 | 5.01 | 0.05 | 9.52 | NM | 9.46 | Deionized water added |
| 4 | 5.00 | 0.08 | 8.55 | NM | 9.21 | Deionized water added |
| 5 | 5.03 | 0.11 | 6.81 | 8.86 | 8.74 | Deionized water added |
| 6 | 5.03 | 0.13 | 6.41 | NM | 8.43 | Deionized water added |
| 7 | 5.03 | 0.16 | 5.98 | NM | 7.82 | Deionized water added |
| 8 | 5.01 | 0.19 | 4.48 | NM | 7.20 | Deionized water added |
| 9 | 5.03 | 0.22 | 4.11 | 6.76 | 6.81 | Deionized water added |
| 10 | 5.01 | 0.24 | 3.86 | NM | 6.28 | Deionized water added |
| 11 | 5.01 | 0.27 | 3.45 | NM | 6.06 | Deionized water added |
| 12 | 5.02 | 0.30 | 3.45 | NM | 5.62 | Deionized water added |
| 13 | 5.02 | 0.33 | 2.84 | 5.18 | 5.20 | Deionized water added |
| 14 | 5.02 | 0.35 | 2.58 | NM | 4.68 | Deionized water added |
| 15 | 4.96 | 0.38 | 2.69 | NM | 4.46 | Deionized water added |
| 16 | 5.00 | 0.40 | 2.66 | NM | 4.20 | Deionized water added |
| 17 | 5.01 | 0.43 | 2.62 | 4.12 | 4.09 | Deionized water added |
| 18 | 5.00 | 0.46 | 2.60 | NM | 3.96 | Deionized water added |
| 19 | 5.00 | 0.49 | 2.51 | NM | 3.78 | Deionized water added |
| 20 | 5.00 | 0.52 | 2.46 | NM | 3.68 | Deionized water added |
| 21 | 5.01 | 0.54 | 2.45 | NM | 3.61 | Deionized water added |
| 22 | 5.01 | 0.00 | 10.43 | NM | 9.96 | Duplicate of Aliquot #1 |
| 23 | 5.01 | 0.05 | 9.77 | NM | 9.67 | Duplicate of Aliquot #3 |
| 24 | 5.03 | 0.16 | 5.04 | NM | 7.53 | Duplicate of Aliquot #7 |
| 25 | 5.02 | 0.27 | 3.39 | NM | 5.75 | Duplicate of Aliquot #11 |
| 26 | 5.02 | 0.38 | 2.82 | NM | 4.55 | Duplicate of Aliquot #15 |
| 27 | 5.04 | 0.49 | 2.54 | NM | 3.74 | Duplicate of Aliquot #19 |
| 28 | 5.03 | 0.54 | 2.46 | NM | 3.59 | Duplicate of Aliquot #21 |

Notes

1. The reference dose determined in Stage 1B was 0.54 meq.
2. The total volume of each solution was 100 mL.
3. All pH measurements are in standard pH units
4. Only five samples for each soil type were measured on day four. The rate of pH change was estimated using these samples.

Abbreviations

g = grams
h = hours
meq = milliequivalent
ml = milliliter
NM = not measured
t = time

**TABLE 17: BUFFERING CAPACITY - STAGE 2 GROUNDWATER RESULTS**[1, 2, 3]

Former Rhone-Poulenc Site, Tukwila, WA

| Aliquot # | Mass Soil (g) | Acidity Added (meq/L GW)[4] | Initial pH (after 1 h) | pH (t=4 days) | pH (t = 12 days)[5] | Corresponding pH for DI Dose (t=5 days)[6] | Notes |
|---|---|---|---|---|---|---|---|
| **Poorly Graded Sand (SP)** | | | | | | | |
| 1 | 5.04 | 181.5 | 6.36 | 6.58 | 6.76 | 4.82 | Groundwater added |
| 2 | 5.05 | 182.7 | 6.21 | 6.40 | 6.60 | 3.52 | Groundwater added |
| 3 | 5.04 | 183.8 | 6.09 | 6.27 | 6.49 | 3.17 | Groundwater added |
| 4 | 5.03 | 184.9 | 6.06 | 6.25 | 6.45 | 2.96 | Groundwater added |
| **Silt and Silty Sand (ML-SM)** | | | | | | | |
| 5 | 5.05 | 181.5 | 6.31 | 6.53 | 7.15 | 8.43 | Groundwater added |
| 6 | 5.03 | 182.7 | 6.23 | 6.45 | 6.67 | 6.28 | Groundwater added |
| 7 | 5.04 | 183.8 | 6.19 | 6.43 | 6.75 | 4.68 | Groundwater added |
| 8 | 5.04 | 184.8 | 6.46 | 6.90 | 7.08 | 3.96 | Groundwater added |

Notes

1. The acidity required to reduce the pH of the groundwater to 6.5 SU is 180.3 meq/L GW.
2. The total volume of each solution was 100 mL, except for aliquot 8, which had a volume of 50 mL due to insufficient groundwater supply.
3. All pH measurements are in standard pH units.
4. The amount of acidity added to the samples containing groundwater was the sum of the quantity required to neutralize the groundwater to a pH of 6.5 SU and the incremental amount calculated for the soil based on Stage 1 testing.
5. Lab did not measure pH on day 5 (due to a communication error). Samples were not mixed between day 4 and day 12.
6. This value is the pH of the samples that contained DI and soil at the corresponding incremental acid dose.

Abbreviations

DI = deionized water

g = grams

h = hours

L = liters

meq = milliequivalent

t = time

GW = groundwater

## TABLE 18: SITE DISSOLVED TOTAL INORGANIC CARBON VARIATION[1]

Former Rhone-Poulenc Site, Tukwila, Washington

| Analysis | Well ID | Date | Concentration (mg/L) | Field pH (SU) |
|---|---|---|---|---|
| **Raw Data** | | | | |
| Dissolved Total Inorganic Carbon SM 5310 B-00 (mg/L) | MW-28[2] | 11/14/2018 | 250.4 | 10.62 |
| | | 11/20/2018 | 247.1 | 10.60 |
| | | 11/30/2018 | 252.5 | 10.49 |
| | | 12/14/2018 | 399 | 10.72 |
| **Calculations** | | | | |
| | | Average: | 287.3 | 10.61 |
| | | Standard Deviation Series: | 64.5 | 0.08 |
| | | Coefficient of Variation: | 22.5% | 0.8% |

Notes
1. Variation in dissolved TIC in MW-28 is assumed to be representative of the site.
2. MW-28 was selected to assess site variation because it has a similar pH to pilot testing wells. The well is screened from 26 to 36 feet bgs in fine to medium grain sand.

Abbreviations
bgs = below ground surface
mg/L = milligrams per liter
SM = standard method
SU = standard pH unit

**TABLE 19: RADIUS OF INFLUENCE ESTIMATION AND UTILIZATION EFFICIENCY CALCULATIONS**

Former Rhone-Poulenc Site, Tukwila, Washington

| Monitoring Well | Baseline TIC (mg/L) | Volume of Groundwater Represented by Monitoring Well[1] (L) | Injection 1 | | | | | Injection 2 | | | | | Injection 3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | pH Change[2] (SU) | Temp Change (°C) | TIC Change[3] (mg/L) | Percent TIC Change[4] | $CO_2$ Delivered[5] (lbs) | pH Change[2] (SU) | Temp Change (°C) | TIC Change[3] (mg/L) | Percent TIC Change[4] | $CO_2$ Delivered[5] (lbs) | pH Change[2] (SU) | Temp Change (°C) | TIC Change[3] (mg/L) | Percent TIC Change[4] | $CO_2$ Delivered[5] (lbs) |
| MW-53 | 247.8 | 73,066 | 1.76 | -0.02 | -18.8 | -7.6% | 0.0 | **-0.37** | 0.04 | 86.6 | **37.8%** | 51.1 | **-0.37** | 0.04 | 249.3 | **79.0%** | 147.1 |
| MW-54 | 14.89 | 40,172 | 0.04 | -0.01 | 81.8 | **549.1%** | 26.5 | **-0.11** | 0.02 | 33.3 | **34.4%** | 10.8 | **-0.40** | 0.01 | 64.5 | **49.7%** | 20.9 |
| IMW-A1-D | 432 | 41,092 | -0.03 | 0.00 | -10.1 | -2.3% | 0.0 | **-0.10** | 0.49 | 59.2 | 14.0% | 0.0 | **-0.38** | 0.29 | 10.5 | 2.2% | 0.0 |
| MW-29 | 153 | 78,197 | -0.01 | -0.01 | -12.3 | -8.1% | 0.0 | 0.01 | -0.01 | -2.2 | -1.6% | 0.0 | 0.00 | -0.01 | -0.8 | -0.6% | 0.0 |
| IMW-A2-D | 395.2 | 16,780 | -0.04 | 0.00 | 0.9 | 0.2% | 0.0 | -0.04 | 0.37 | 5.5 | 1.4% | 0.0 | -0.04 | 0.73 | 17.3 | 4.3% | 0.0 |
| IMW-A2-S | 185.7 | 73,724 | 0.02 | 0.00 | -28.8 | -15.5% | 0.0 | **-0.29** | 0.00 | 4.1 | 2.6% | 0.0 | **-0.29** | 0.01 | 10.4 | 6.5% | 0.0 |
| IMW-B2-S | 119.3 | 147,134 | -0.02 | 0.00 | -22.0 | -18.4% | 0.0 | -0.03 | 0.00 | 7.0 | 7.2% | 0.0 | 0.00 | 0.00 | -10.7 | -10.3% | 0.0 |
| IMW-B1-D | 443 | 163,482 | -0.07 | 0.00 | -28.1 | -6.3% | 0.0 | -0.02 | -0.01 | 61.8 | 14.9% | 0.0 | -0.01 | 0.00 | 12.1 | 2.5% | 0.0 |
| IMW-B1-S | 249.7 | 245,224 | 0.06 | -0.03 | -16.6 | -6.6% | 0.0 | 0.25 | -0.01 | 7.9 | 3.4% | 0.0 | 0.21 | 0.01 | -30.7 | -12.7% | 0.0 |
| IMW-C1-S | 203.2 | 97,989 | 0.08 | -0.03 | -15.5 | -7.6% | 0.0 | -0.06 | -0.01 | -2.3 | -1.2% | 0.0 | -0.08 | 0.01 | -2.4 | -1.3% | 0.0 |
| Vent | 141.7 | 90,082 | 0.01 | 0.00 | -2.6 | -1.8% | 0.0 | 0.02 | -0.01 | -4.0 | -2.9% | 0.0 | 0.00 | -0.01 | -5.6 | -4.1% | 0.0 |
| **Total $CO_2$ Delivered (lbs)** | | | | | | | 26.5 | | | | | 61.9 | | | | | 168.1 |
| **Total $CO_2$ Injected (lbs)** | | | | | | | 196.0 | | | | | 548.8 | | | | | 731.7 |
| **Utilization Efficiency** | | | | | | | 14% | | | | | 11% | | | | | 23% |

## TABLE 19: RADIUS OF INFLUENCE ESTIMATION AND UTILIZATION EFFICIENCY CALCULATIONS

Former Rhone-Poulenc Site, Tukwila, Washington

| | | | Injection 4 | | | | | Injection 5 | | | | | Phase 3 Injections | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Monitoring Well | Baseline TIC (mg/L) | Volume of Groundwater Represented by Monitoring Well[1] (L) | pH Change[2] (SU) | Temp Change (°C) | TIC Change[3] (mg/L) | Percent TIC Change[4] | $CO_2$ Delivered[5] (lbs) | pH Change[2] (SU) | Temp Change (°C) | TIC Change[3] (mg/L) | Percent TIC Change[4] | $CO_2$ Delivered[5] (lbs) | TIC Baseline | pH Change[6] (SU) | TIC Change[7] (mg/L) | Percent TIC Change[4] | $CO_2$ Delivered[5] (lbs) |
| MW-53 | 247.8 | 73,066 | **-0.27** | 0.03 | 116.5 | 20.6% | 0.0 | **-0.15** | 0.03 | 65.8 | 9.7% | 0.0 | 564.2 | **-0.47** | -59.7 | -10.6% | 0.0 |
| MW-54 | 14.89 | 40,172 | **-0.72** | 0.03 | 49.5 | **25.5%** | 16.1 | **-0.60** | -0.01 | 83.4 | **34.2%** | 27.1 | 137.2 | **-1.40** | 176.4 | **128.6%** | 57.2 |
| IMW-A1-D | 432 | 41,092 | **-0.25**[8] | 0.33 | 330.9 | **67.3%** | 109.8 | **-0.58** | 0.21 | 436.5 | **53.1%** | 144.9 | 617.1 | **-1.32** | 1,480.9 | **240.0%** | 491.6 |
| MW-29 | 153 | 78,197 | 0.01 | -0.01 | 13.9 | 10.1% | 0.0 | 0.00 | -0.01 | 30.4 | 20.1% | 0.0 | 142.6 | **-0.32** | 17.5 | 12.3% | 0.0 |
| IMW-A2-D | 395.2 | 16,780 | **-0.66**[8] | 0.59 | 211.7 | **50.5%** | 28.7 | **-1.09** | 0.16 | 1,218.4 | **193.2%** | 165.1 | 2422.0 | **-1.75** | 882.0 | **36.4%** | 119.5 |
| IMW-A2-S | 185.7 | 73,724 | **-0.27** | 0.00 | 18.0 | 10.5% | 0.0 | **-0.12** | 0.03 | 52.7 | **27.8%** | 31.4 | 242.5 | **-0.60** | 75.0 | **30.9%** | 44.7 |
| IMW-B2-S | 119.3 | 147,134 | 0.00 | -0.01 | 18.6 | 19.9% | 0.0 | -0.03 | -0.01 | 24.6 | 21.9% | 0.0 | 114.5 | 0.01 | 34.2 | **29.9%** | 40.6 |
| IMW-B1-D | 443 | 163,482 | -0.03 | 0.01 | -19.0 | -3.9% | 0.0 | -0.02 | 0.04 | -44.8 | -9.5% | 0.0 | 264.1 | **-0.28** | 874.9 | **331.3%** | 1155.4 |
| IMW-B1-S | 249.7 | 245,224 | 0.98 | -0.03 | 11.7 | 5.6% | 0.0 | 0.76 | -0.01 | 24.6 | 11.1% | 0.0 | 223.3 | **-1.00** | 43.8 | 19.6% | 0.0 |
| IMW-C1-S | 203.2 | 97,989 | 0.08 | -0.03 | 6.2 | 3.4% | 0.0 | -0.06 | -0.01 | 18.6 | 9.8% | 0.0 | 188.8 | 0.06 | 30.0 | 15.9% | 0.0 |
| Vent | 141.7 | 90,082 | 0.00 | -0.01 | 10.4 | 8.0% | 0.0 | 0.00 | -0.02 | 19.7 | 14.1% | 0.0 | 152.7 | 0.02 | 31.8 | 20.8% | 0.0 |
| **Total $CO_2$ Delivered (lbs)** | | | | | | | 154.6 | | | | | 368.5 | | | | | 1,909.1 |
| **Total $CO_2$ Injected (lbs)** | | | | | | | 960.3 | | | | | 1221.6 | | | | | 16,457 |
| **Utilization Efficiency** | | | | | | | 16% | | | | | 30% | | | | | 12% |

Notes

1. Volumes calculated using Figure 43 and Calculation 1.
2. Phase 1 pH change is the difference between the 30-minute average pH before the injection event and the pH 24 hours after the injection event.
3. Phase 1 TIC change is the difference between the TIC measured in groundwater samples collected before and after each injection.
4. Percent changes in dissolved TIC larger than 22.5% were considered significant, and are in bold. pH decreases of greater than 0.1 SU are also in bold.
5. Negative values and changes in TIC less than 22.5% were assumed to be zero when calculating utilization efficiency.
6. Phase 3 pH change is the difference between post Phase 2 samples and post Phase 3 samples.
7. Phase 3 TIC change is the difference between post Phase 3 samples and post Phase 2 samples.
8. The pH decreased in IMW-A2-D and A1-D after groundwater sampling; therefore this value is the difference between the 30-minute average pH before injection events 4 and 5.

Abbreviations

°C = degrees Celsius

$CO_2$ = carbon dioxide

L = liters

lbs = pounds

mg/L = milligrams per liter

SU = standard units

TIC = total inorganic carbon

## TABLE 20: WELLHEAD PRESSURE DATA[1]

Former Rhone-Poulenc Site, Tukwila, Washington

Results reported in pounds per square inch gauge (psig)

| Well ID | Injection 1 | | Injection 2 | | Injection 3 | | Injection 4 | | Injection 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max[2] | Min[3] | Max[2] | Min[3] | Max[2] | Min[3] | Max[2] | Min[3] | Max[2] | Min[3] |
| MW-54 | 0.04 | -0.27 | 0.85 | -1.07 | 0.37 | -0.42 | 0.18 | -0.24 | 1.07 | -0.9 |
| IMW-A2-D | 0.04 | -0.26 | 0.35 | -0.05 | 0.16 | -0.12 | 0.22 | -0.22 | 1.07 | -0.09 |
| IMW-A1-D | 0 | -0.35 | 0.24 | -0.09 | 0.11 | -0.14 | 0.14 | -0.17 | 0.07 | -0.14 |
| IMW-B1-D | 0.02 | -0.17 | 0.32 | 0 | 0.16 | -0.16 | 0 | -0.16 | 0.12 | -0.12 |
| MW-53 | 0.10 | -0.02 | 0.00 | -0.06 | 0.12 | -0.11 | 0.06 | -0.01 | 0.07 | -0.01 |
| MW-29 | 0.15 | -0.16 | 0.17 | -0.10 | 0.09 | -0.12 | 0.10 | -0.16 | 0.09 | -0.05 |
| IMW-A2-S | 0.09 | -0.03 | 0.24 | -0.02 | 0.13 | -0.18 | 0.04 | -0.09 | 0.11 | -0.14 |
| IMW-B2-S | 0.08 | -0.22 | 0.16 | -0.23 | 0.16 | -0.17 | 0.09 | -0.26 | 0.28 | -0.08 |
| IMW-B1-S | 0.1 | -0.22 | 0.23 | -0.11 | 0.1 | -0.17 | 0.16 | -0.16 | 0.13 | -0.08 |
| IMW-C1-S | 0.02 | -0.15 | 0.2 | -0.06 | 0.08 | -0.1 | 0.07 | -0.14 | 0.09 | -0.06 |
| Vent | 0.03 | -0.17 | 0.16 | -0.17 | 0.16 | -0.08 | 0.36 | -0.17 | 0.21 | -0.11 |

Notes

1. Pressure was measured using a handheld digital manometer except in MW-53 and IMW-A2-S, where a pressure transducer was used.
2. Maximum wellhead pressure is the largest pressure recorded during the injection event and the 30-minute period after injection stopped.
3. Minimum wellhead pressure is the lowest pressure recorded during the injection event and the 30-minute period after injection stopped.

Abbreviations

Max = maximum
Min = minimum
psig = pounds per square inch gauge

# TABLE 21: SLUG TEST RESULTS

Former Rhone-Poulenc Site, Tukwila, Washington

| Parameter | Injection Well | | | | IMW-A1-D | | | | MW-53 | | | | MW-54 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre/post injection | Pre injection | | Post injection | | Pre injection | | Post injection | | Pre injection | | Post injection | | Pre injection | | Post injection | |
| Slug test date | 3/26/2018 | | 1/17/2019 | | 3/26/2018 | | 1/17/2019 | | 3/26/2018 | | 1/17/2019 | | 3/21/2018 | | 1/16/2019 | |
| Slug in/out | Slug in | Slug out | Slug in | Slug out | Slug in | Slug out | Slug in | Slug out | Slug in | Slug out | Slug in | Slug out | Slug in | Slug out | Slug in | Slug out |
| Hydraulic conductivity (cm/sec) | 2.12E-04 | 5.75E-05 | 3.88E-05 | 6.07E-05 | 2.69E-06 | 6.63E-07 | 2.54E-07 | 1.29E-06 | 1.92E-02 | 5.66E-02 | 3.07E-02 | 5.95E-02 | 1.83E-05 | 8.48E-06 | 2.74E-05 | 1.15E-05 |
| Hydraulic conductivity (percent change)[2] | N/A | N/A | 82% | -6% | N/A | N/A | 91% | -94% | N/A | N/A | -60% | -5% | N/A | N/A | -49% | -36% |
| Slug test duration analyzed (sec) | 259.5 | 2634.0 | 2115.0 | 1740.0 | 7045.0 | 1676.0 | 7020.0 | 7140.0 | 2.3 | 1.5 | 2.5 | 2.0 | 2791.5 | 3315.5 | 3615.0 | 5415.0 |
| Displacement rebound | 74.5% | 98.0% | 96.0% | 97.5% | 37.1% | 3.5% | 4.1% | 20.6% | 90.6% | 85.7% | 94.0% | 94.0% | 86.4% | 72.4% | 93.8% | 89.5% |

Notes

1. All analyses were done based on the following assumptions:
    1) Unconfined aquifer, Bouwer-Rice slug test method on Aqtesolv
    2) Aquifer thickness of 60 ft
    3) 1:1 vertical and horizontal anisotropy ratio
    4) 0 ft radius downhole equipment
    5) 0 ft inside radius of packer
    6) Outer radius of well skin = radius of filter pack
    7) Applying correction for frictional well loss with kinematic viscosity:1.2e-006 square m/sec and gravitational acceleration: 9.80665 m/sec squared
2. Percent changes is the difference between post-injection hydraulic conductivity and pre-injection hydraulic conductivity.

Abbreviations

cm = centimeter

ft = feet

m = meter

sec = second

# Calculations

# CALCULATION SHEET

amec foster wheeler

TITLE $CO_2$ Utilization Calculations – Injection 2

CALC. NO. REVISION 1 PAGE NO. 1 OF 3

PRE. BY WMY DATE 8/10/18 CHKD. BY EOT DATE 9/13/18

Objective

- Determine the percent $CO_2$ utilization over the course of the second injection.

Measurements

- dimensions/areas of representative groundwater presented in Figure 44. (Summarized in table below)
- Change in dissolved TIC readings before & after injection 2 presented in Table 2. (Summarized below)
- Total mass $CO_2$ injected = 548.8 lbs as presented in Table 1.

Data Summary

| Well ID | Area represented | Pre-INJ 2 TIC | Post-INJ 2 TIC | Change in TIC |
|---|---|---|---|---|
| MW-53 | 344.0 ft² | 229.0 mg/L | 315.6 mg/L | 86.5 mg/L |
| MW-54 | 283.7 ft² | 96.95 mg/L | 129.9 mg/L | 33.3 mg/L |
| IMW-A1-D | 290.2 ft² | 421.9 mg/L | 481.1 mg/L | 59.2 mg/L |
| MW-29 | 613.6 ft² | 140.3 mg/L | 138.1 mg/L | -2.2 mg/L |
| IMW-A2-D | 118.5 ft² | 396.1 mg/L | 401.6 mg/L | 5.5 mg/L |
| IMW-A2-S | 347.1 ft² | 156.9 mg/L | 161 mg/L | 4.1 mg/L |
| IMW-B2-S | 1,154.5 ft² | 97.30 mg/L | 104.3 mg/L | 7.0 mg/L |
| IMW-B1-D | 1,154.5 ft² | 414.9 mg/L | 476.7 mg/L | 61.8 mg/L |
| IMW-B1-S | 1,154.5 ft² | 233.1 mg/L | 241.0 mg/L | 7.9 mg/L |
| IMW-C1-S | 768.9 ft² | 183.7 mg/L | 185.4 mg/L | -2.3 mg/L |
| Vent | 706.9 ft² | 139.1 mg/L | 135.1 mg/L | -4.0 mg/L |

Assumptions

- Groundwater is representative of sampling results of nearest observation well as presented in Figure 44.
- Water level is 16' bgs
- Soil porosity = 0.5
- All increases in TIC are caused by $CO_2$ injection.
- Negative changes in TIC were assumed to be zero if the change in pH was < 0.1 SU.
- Changes in TIC less than 4.7% were assumed to be zero.

# CALCULATION SHEET

TITLE: $CO_2$ Utilization Calculations – Injection 2

CALC. NO. | REVISION 1 | PAGE NO. 2 OF 3

PRE. BY WMY | DATE 8/10/18 | CHKD. BY ZOT | DATE 9/13/18

amec foster wheeler

Solve

1) Find Groundwater volumes

Volume GW = (Height)(Area)(porosity)

| Well | Calculation | Volume (L) |
|---|---|---|
| MW-53 | (344.0 ft²)(40 ft − 25 ft)(0.5)(28.32 L/ft³) | 73,066 |
| MW-54 | (283.7 ft²)(50 ft − 40 ft)(28.32 L/ft³)(0.5) | 40,172 |
| IMW-A1-D | (290.2 ft²)(50 ft − 40 ft)(0.5)(28.32 L/ft³) | 41,092 |
| MW-29 | (613.6 ft²)(25 ft − 16 ft)(0.5)(28.32 ft³/L) | 78,197 |
| IMW-A2-D | (118.5 ft²)(50 ft − 40 ft)(0.5)(28.32 ft³/L) | 16,780 |
| IMW-A2-S | (347.1 ft²)(40 ft − 25 ft)(0.5)(28.32 ft³/L) | 73,724 |
| IMW-B2-S | (1,154.5 ft²)(25 ft − 16 ft)(0.5)(28.32 ft³/L) | 147,134 |
| IMW-B1-D | (1,154.5 ft²)(50 ft − 40 ft)(0.5)(28.32 ft³/L) | 163,482 |
| IMW-B1-S | (1,154.5 ft²)(40 ft − 25 ft)(0.5)(28.32 ft³/L) | 245,224 |
| IMW-C1-S | (768.9 ft²)(25 ft − 16 ft)(0.5)(28.32 L/ft³) | 97,989 |
| Vent | (706.9 ft²)(25 ft − 16 ft)(28.32/ft³)(0.5) | 90,082 |

2) Find amount of $CO_2$ dissolved in each section.

$$\text{"C"} = \frac{1\ \text{mol C}}{12{,}011\ \text{mg C}} \cdot \frac{\text{mol } CO_2}{\text{mol C}} \cdot \frac{44{,}009\ \text{mg } CO_2}{\text{mol } CO_2} \cdot \frac{1\ \text{lb } CO_2}{453592\ \text{mg } CO_2} = 8.07787 \times 10^{-6}\ \frac{\text{lb } CO_2}{\text{mg C}}$$

| Well | Calculation | $CO_2$ Delivered (lb) | Notes |
|---|---|---|---|
| MW-53 | (73,066 L)("C" lb $CO_2$/mg C)(86.6 mg C/L) | 51.1 | |
| MW-54 | (40,172 L)("C" lb $CO_2$/mg C)(33.3 mg C/L) | 10.8 | |
| IMW-A1-D | (41,092 L)("C" lb $CO_2$/mg C)(59.2 mg C/L) | 19.7 | |
| MW-21 | (78,197 L)("C" lb $CO_2$/mg C)(−2.2 mg C/L) | ~~0.0~~ | pH did not change ∴ 0 |
| IMW-A2-D | (16,780 L)("C" lb $CO_2$/mg C)(5.5 mg C/L) | ~~0.7~~ | change in TIC < 4.7% |
| IMW-A2-S | (73,724 L)("C" lb $CO_2$/mg C)(4.1 mg C/L) | ~~2.4~~ | change in TIC < 4.7% |
| IMW-B2-S | (147,134 L)("C" lb $CO_2$/mg C)(7.0 mg C/L) | 8.3 | |
| IMW-B1-D | (163,482 L)("C" lb $CO_2$/mg C)(61.8 mg C/L) | 81.6 | |
| IMW-B1-S | (245,224 L)("C" lb $CO_2$/mg C)(7.9 mg C/L) | ~~15.6~~ | Change in TIC < 4.7% |
| IMW-C1-S | (97,989 L)("C" lb $CO_2$/mg C)(−2.3 mg C/L) | ~~−1.8~~ | pH did not change ∴ 0 |
| Vent | (90,082 L)("C" lb $CO_2$/mg C)(−4.0 mg C/L) | ~~−2.9~~ | pH did not change ∴ 0 |
| | Total: | 171.5 | lbs $CO_2$ |

# CALCULATION SHEET

amec foster wheeler

TITLE $CO_2$ Utilization Calculations - Injection 2

CALC. NO. REVISION 1 PAGE NO. 3 OF 3

PRE. BY WMY DATE 8/10/18 CHKD. BY ZCT DATE 9/13/18

Solve (continued)

3) Determine utilization efficiency

$$\text{Utilization efficiency} = \frac{CO_2 \text{ Delivered}}{CO_2 \text{ Injected}} \times 100\%$$

$$\frac{171.5 \text{ lbs } CO_2}{548.8 \text{ lbs } CO_2} \times 100\% = 31.25\%$$

| INJECTION 2 UTILIZATION EFFICIENCY | = 31 % |
|---|---|

Reviewed by: KMT 9/13/18

# Calculation Worksheet

| Document # | Calculation 2 | Revision | 0 |
|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| TITLE: | $CO_2$ Utilization Calculations - Pilot Study | | | SHEET: | 1 OF 1 |
| PREPARED BY: (Print & Sign) | William Young *William Young* | DATE: 15-May-20 | CHECKED BY: (Print & Sign) | Brady Lubenow | DATE: 15-May-20 |

**Objective:** Estimate the $CO_2$ utilization efficiency during pilot scale testing using the total mass of $CO_2$ injected and the theoretical acid demand of the pilot testing area if a radius of influence is assumed.

**Assumptions:**

- Soil porosity of both SP and ML-SM soil is 0.5.
- Depth of 10 feet (corresponding to 40 to 50 feet bgs and high pH target area).
- Soil buffering capacity was completely neutralized.
- SP soil extends from water table to 43 feet.
- ML-SM soil is present from 43 feet to 50 feet.
- Specific gravity of both SP and ML-SM soil is 2.5.

**Acronyms**

| | | | |
|---|---|---|---|
| $H_2CO_3$ | Carbonic acid | lb | pound |
| $CO_2$ | Carbon dioxide | meq | milliequivalents |
| eq | equivalents | ML-SM | silty sand |
| ft | feet | mol | mole |
| $ft^3$ | cubic feet | mg | milligrams |
| kg | kilograms | SP | sand |
| L | liters | | |

**Constants**

| | | |
|---|---|---|
| Molar Mass $CO_2$ | 44,009 | mg/mol |
| Milligrams in a pound | 453,592 | mg/lb |
| Moles carbonic acid per mole carbon dioxide | 1 | mol $H_2CO_3$/mol $CO_2$ |
| Acidity per mol carbonic acid | 2 | eq/mol $H_2CO_3$ |

**Measurements**

| | | |
|---|---|---|
| Post Phase 4 IMW-A1-D pH | 8.1 | SU |
| Theoretical SP soil acid demand at endpoint | 0.008 | meq/g |
| Theoretical ML-SM soil acid demand at endpoint | 0.0298 | meq/g |
| Theoretical groundwater acid demand at endpoint | 163.5 | meq/L |
| Post Phase 4 IMW-A2-D pH | 7.0 | SU |
| Theoretical SP soil acid demand at endpoint | 0.011 | meq/g |
| Theoretical ML-SM soil acid demand at endpoint | 0.0342 | meq/g |
| Theoretical groundwater acid demand at endpoint | 175.4 | meq/L |
| Post Phase 4 MW-54 pH | 7.6 | SU |
| Theoretical SP soil acid demand at endpoint | 0.009 | meq/g |
| Theoretical ML-SM soil acid demand at endpoint | 0.0405 | meq/g |
| Theoretical groundwater acid demand at endpoint | 168.9 | meq/L |
| Post Phase 4 IMW-B1-D pH | 11.5 | SU |
| Theoretical SP soil acid demand at endpoint | 0 | meq/g |
| Theoretical ML-SM soil acid demand at endpoint | 0 | meq/g |
| Theoretical groundwater acid demand at endpoint | 4.8 | meq/L |
| Area represented by IMW-A1-D | 290.2 | $ft^2$ |
| Area represented by IMW-A2-D | 118.5 | $ft^2$ |
| Area represented by MW-54 | 238.7 | $ft^2$ |
| Area represented by IMW-B1-D | 1154.5 | $ft^2$ |
| Pounds of $CO_2$ injected during Phases 1 and 3 | 20,115 | lbs |

***1) Calculate the volume of groundwater and mass of each soil type within each zone***

| | | |
|---|---|---|
| Volume of IMW-A1-D = (Area)(Depth) = (290.2 $ft^2$) (10 ft)= | 2,902 | $ft^3$ |
| Volume Groundwater = (Volume)(Porosity) = (2,902 $ft^3$)(0.5) | 1,451 | $ft^3$ |
| | 41,088 | L |
| Volume of IMW-A1-D SP soil = (Area)(Depth)(1-Porosity) = (290.2$ft^2$)(3ft)(0.5)(28.3168 L/ $ft^3$) | 12,326 | L |
| Mass = (Volume)(Specific Gravity)(Density of Water) = (12,326 L)(2.5)(1 kg/L) | 30,816 | kg |
| Volume of IMW-A1-D ML-SM soil = (Area)(Depth)(1-Porosity) = (290.2$ft^2$)(7ft)(0.5)(28.3168 L/ $ft^3$) | 28,761 | L |
| Mass = (Volume)(Specific Gravity)(Density of Water) = (28,761 L)(2.5)(1 kg/L) | 71,903 | kg |

| | |
|---|---|
| Volume of IMW-A2-D = (Area)(Depth) = (118.5 $ft^2$) (10 ft)= | 1,185 $ft^3$ |
| Volume Groundwater = (Volume)(Porosity) = (2,902 $ft^3$)(0.5) | 593 $ft^3$ |
| | 16,778 L |
| Volume of IMW-A2-D SP soil = (Area)(Depth)(1-Porosity) = (118.5$ft^2$)(3ft)(0.5)(28.3168 L/ $ft^3$) | 5,033 L |
| Mass = (Volume)(Specific Gravity)(Density of Water) = (5,033 L)(2.5)(1 kg/L) | 12,583 kg |
| Volume of IMW-A2-D ML-SM soil = (Area)(Depth)(1-Porosity) = (118.5$ft^2$)(7ft)(0.5)(28.3168 L/ $ft^3$) | 11,744 L |
| Mass = (Volume)(Specific Gravity)(Density of Water) = (11,744 L)(2.5)(1 kg/L) | 29,361 kg |
| Volume of MW-54 = (Area)(Depth) = (238.7 $ft^2$) (10 ft)= | 2,387 $ft^3$ |
| Volume Groundwater = (Volume)(Porosity) = (2,378 $ft^3$)(0.5) | 1,194 $ft^3$ |
| | 33,796 L |
| Volume of MW-54 SP soil = (Area)(Depth)(1-Porosity) = (238.7$ft^2$)(3ft)(0.5) | 10,139 L |
| Mass = (Volume)(Specific Gravity)(Density of Water) = (10,139 L)(2.5)(1 kg/L) | 25,347 kg |
| Volume of MW-54 ML-SM soil = (Area)(Depth)(1-Porosity) = (238.7$ft^2$)(7ft)(0.5) | 23,657 L |
| Mass = (Volume)(Specific Gravity)(Density of Water) = (23,657 L)(2.5)(1 kg/L) | 59,143 kg |
| Volume of IMW-B1-D = (Area)(Depth) = (1,154.5 $ft^2$) (10 ft)= | 11,545 $ft^3$ |
| Volume Groundwater = (Volume)(Porosity) = (11,545 $ft^3$)(0.5) | 5,773 $ft^3$ |
| | 163,459 L |
| Volume of MW-54 SP soil = (Area)(Depth)(1-Porosity) = (1154.5$ft^2$)(3ft)(0.5) | 49,038 L |
| Mass = (Volume)(Specific Gravity)(Density of Water) = (49,038 L)(2.5)(1 kg/L) | 122,594 kg |
| Volume of MW-54 ML-SM soil = (Area)(Depth)(1-Porosity) = (1154.5$ft^2$)(7ft)(0.5) | 114,421 L |
| Mass = (Volume)(Specific Gravity)(Density of Water) = (114,421 L)(2.5)(1 kg/L) | 286,053 kg |

***2) Calculate the total theoretical acid demand within each zone***

| | |
|---|---|
| IMW-A1-D | |
| Acidity groundwater = (volume groundwater)(acid demand) | 6,716 eq |
| Acidity SP = (mass SP soil)(acid demand) | 252 eq |
| Acidity ML-SM = (mass ML-SM soil)(acid demand) | 2,140 eq |
| IMW-A2-D | |
| Acidity groundwater = (volume groundwater)(acid demand) | 2,943 eq |
| Acidity SP = (mass SP soil)(acid demand) | 139 eq |
| Acidity ML-SM = (mass ML-SM soil)(acid demand) | 1,005 eq |
| MW-54 | |
| Acidity groundwater = (volume groundwater)(acid demand) | 5,709 eq |
| Acidity SP = (mass SP soil)(acid demand) | 240 eq |
| Acidity ML-SM = (mass ML-SM soil)(acid demand) | 2,396 eq |
| IMW-B1-D | |
| Acidity groundwater = (volume groundwater)(acid demand) | 788 eq |
| Acidity SP = (mass SP soil)(acid demand) | 0 eq |
| Acidity ML-SM = (mass ML-SM soil)(acid demand) | 0 eq |
| Total acidity in lower aquifer zone | 22,328 eq |

***3) Calculate the acidity injected***

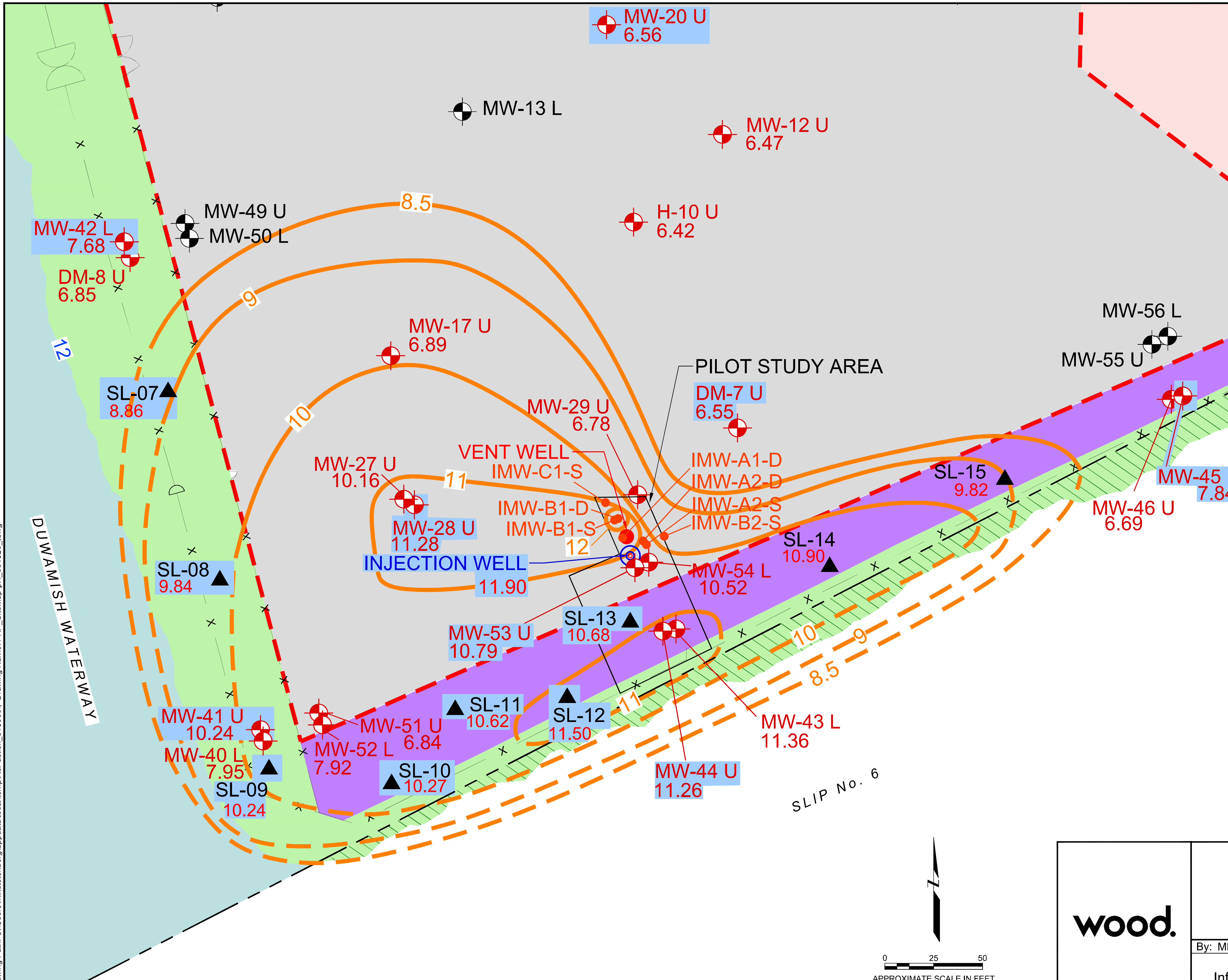
Acidity injected =
(20,115 lbs $CO_2$)(453,592 mg $CO_2$/lb $CO_2$)(1 mol $CO_2$/12,011 mg $CO_2$) 414,643 eq
(1 mol $H_2CO_3$/1 mol $CO_2$)(2 eq/mol $H_2CO_3$)

***4) Calculate the utilization efficency***

Utilization efficiency = (theoretical acid demand) / (acidity injected) = (22,328 eq) / (414,643 eq) 5.4%

# Figures

EXPLANATION
PROPERTY LINE
APPROXIMATE LOCATION OF BARRIER WALL
FENCE
SL-08 SHORELINE AREA GROUNDWATER SAMPLING LOCATION, 2011
HISTORIC SAMPLING LOCATION
SL-01 SHORLINE AREA SOIL SAMPLING LOCATION
IMW A1 PILOT STUDY WELLS $CO_2$ INJECTION MONITORING WELL
$CO_2$ INJECTION VENT WELL
$CO_2$ INJECTION WELL
MONITORING WELL NETWORK
MONITORING WELL LOCATION
EXTRACTION WELL LOCATION
U UPPER ZONE MONITORING POINT
L LOWER ZONE MONITORING POINT
KEY
UPLAND AREA
HCIM AREA
SEDIMENT AREA
SHORELINE AREA
PAVED SHORELINE AREA
SLIP 6 SHORELINE AREA OWNED BY THE BOEING COMPANY UNPAVED
DUWAMISH WATERWAY
SLIP No. 6
PILOT STUDY AREA
VENT WELL
INJECTION WELL 11.90
A
A'
B
B'
A01-04
MW-39 L 7.64
MW-38R U 7.36
MW-48 L
MW-47 U
MW-59 U
A2 U
DM-3A U/DM-3B D
MW-58 U
B1B D
B1A U
EX-1 U
EX-2 U
DM-4 U
B2 U
MW-57 U
DM-5 U
MW-22 U
MW-20 U 6.56
EX-3 U 6.69
B6 U
MW-13 L
MW-12 U 6.47
MW-64
MW-49 U
MW-50 L
H-10 U 6.42
MW-66
MW-65
MW-42 L 7.68
DM-8 U 6.85
MW-17 U 6.89
MW-55 U
MW-56 L
SL-07 8.86
MW-29 U 6.78
DM-7 U 6.55
MW-45 L 7.84
MW-46 U 6.69
MW-27 U 10.16
IMW-C1-S
IMW-B1-D
IMW-B1-S
IMW-A1-D
IMW-A2-D
IMW-A2-S
IMW-B2-S
MW-28 U 11.28
SL-15 9.82
SL-14 10.60
SL-08 9.84
MW-54 L 10.52
MW-53 U 10.79
SL-13 10.68
MW-43 L 11.36
MW-44 U 11.26
MW-41 U 10.24
MW-40 L 7.95
SL-09 10.24
MW-51 U 9.84
MW-52 L 7.92
SL-11 10.62
SL-12 11.50
SL-10 10.27
SL-01
SL-02
SL-03
SL-04
SL-05
SL-06
N
0 50 100
APPROXIMATE SCALE IN FEET
wood.
SITE LAYOUT
Former Rhone-Poulenc Site
Tukwila, Washington
By: MDS
Date: 05/15/20
Project No. 08769
Wood Environment & Infrastructure Solutions, Inc.
Figure 1
Plot Date: 05/15/20 - 7:52am, Plotted by: mike.stenberg
Drawing Path: C:\Users\mike.stenberg\Desktop\Civil 3D Projects\Wood\FRP\FRP_SiteMap-PH_051320\, Drawing Name: FRP_SiteMap-pH_051320_.dwg




## EXPLANATION

- PROPERTY LINE
- APPROXIMATE LOCATION OF BARRIER WALL
- X FENCE
- GROUNDWATER pH LEVELS GROUNDWATER pH CONTOUR (DASHED WHERE INFERRED) CONTOUR INTERVAL 1.0 STANDARD UNITS
- MW-45 L 7.34 — HIGHLIGHTED SAMPLE LOCATIONS USED TO GENERATE pH CONTOURS
- SL-08 9.84 — SHORELINE AREA GROUNDWATER SAMPLING LOCATION, 2011
- MW-54 L 10.52 — MAXIMUM OBSERVED FROM MARCH 2008 TO PRE-PILOT STUDY pH VALUE

PILOT STUDY WELLS

- IMW A1 — $CO_2$ INJECTION MONITORING WELL
- $CO_2$ INJECTION VENT WELL
- $CO_2$ INJECTION WELL

MONITORING WELL NETWORK

- MONITORING WELL LOCATION
- EXTRACTION WELL LOCATION
- U — UPPER ZONE MONITORING POINT
- L — LOWER ZONE MONITORING POINT

KEY

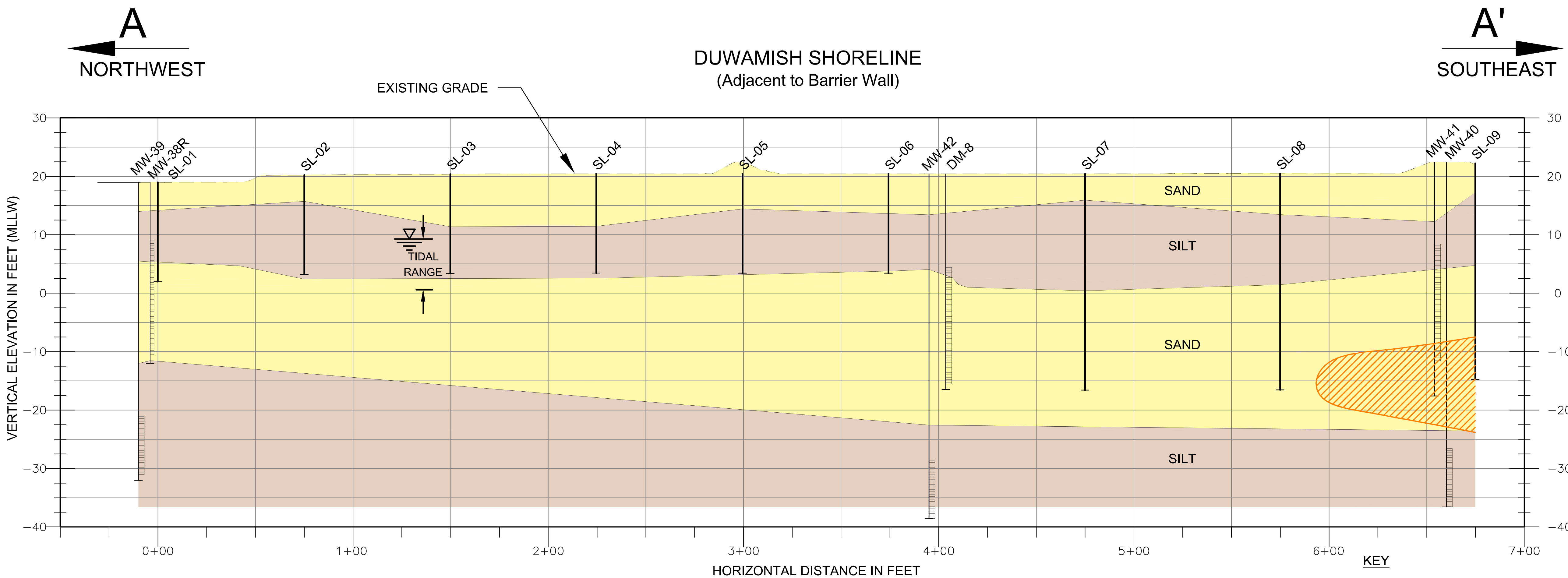
- UPLAND AREA
- HCIM AREA
- SEDIMENT AREA
- SHORELINE AREA
- PAVED SHORELINE AREA
- SLIP 6 SHORELINE AREA OWNED BY THE BOEING COMPANY UNPAVED

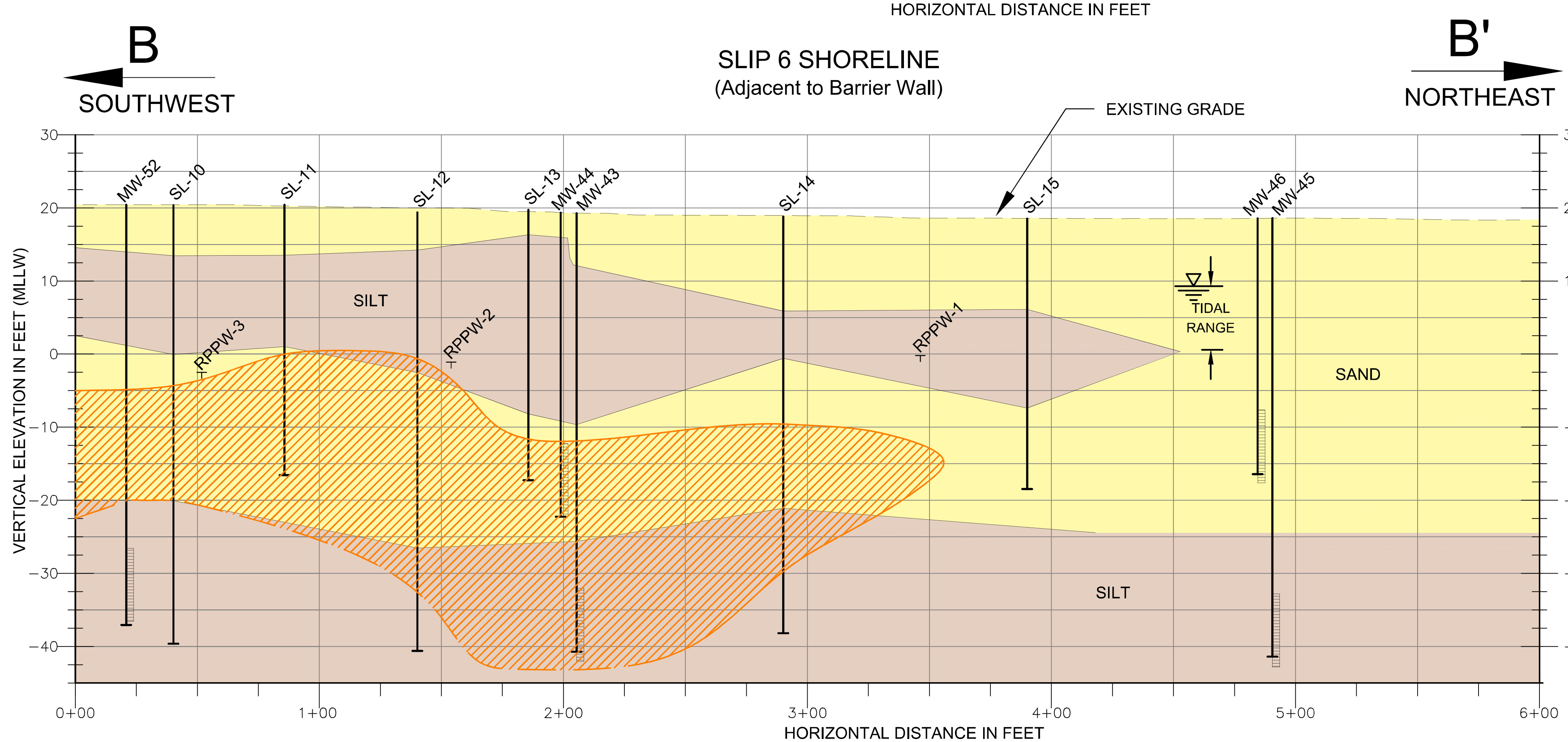
wood.

HIGH pH GROUNDWATER AREA
Former Rhone-Poulenc Site
Tukwila, Washington

| By: MDS | Date: 05/15/20 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 2 |

Plot Date: 05/15/20 - 10:36am, Plotted by: mike.stenberg
Drawing Path: C:\Users\mike.stenberg\appdata\local\temp\AcPublish_513968\, Drawing Name: FRP_SiteMap-pH_051320_.dwg




KEY

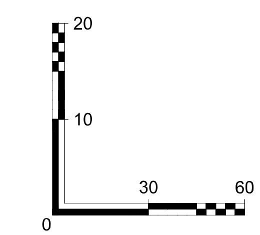
RPPW-1 — POREWATER SAMPLING LOCATION PROJECTED ONTO THE LINE OF CROSS SECTION.

WELL SCREEN INTERVAL

SAND (SP)

SILT (ML-SM)

AREA AFFECTED BY CAUSTIC WHERE pH IS GREATER THAN 8.5 STANDARD UNITS



APPROXIMATE SCALE IN FEET
VERTICAL EXAGGERATION = 3X

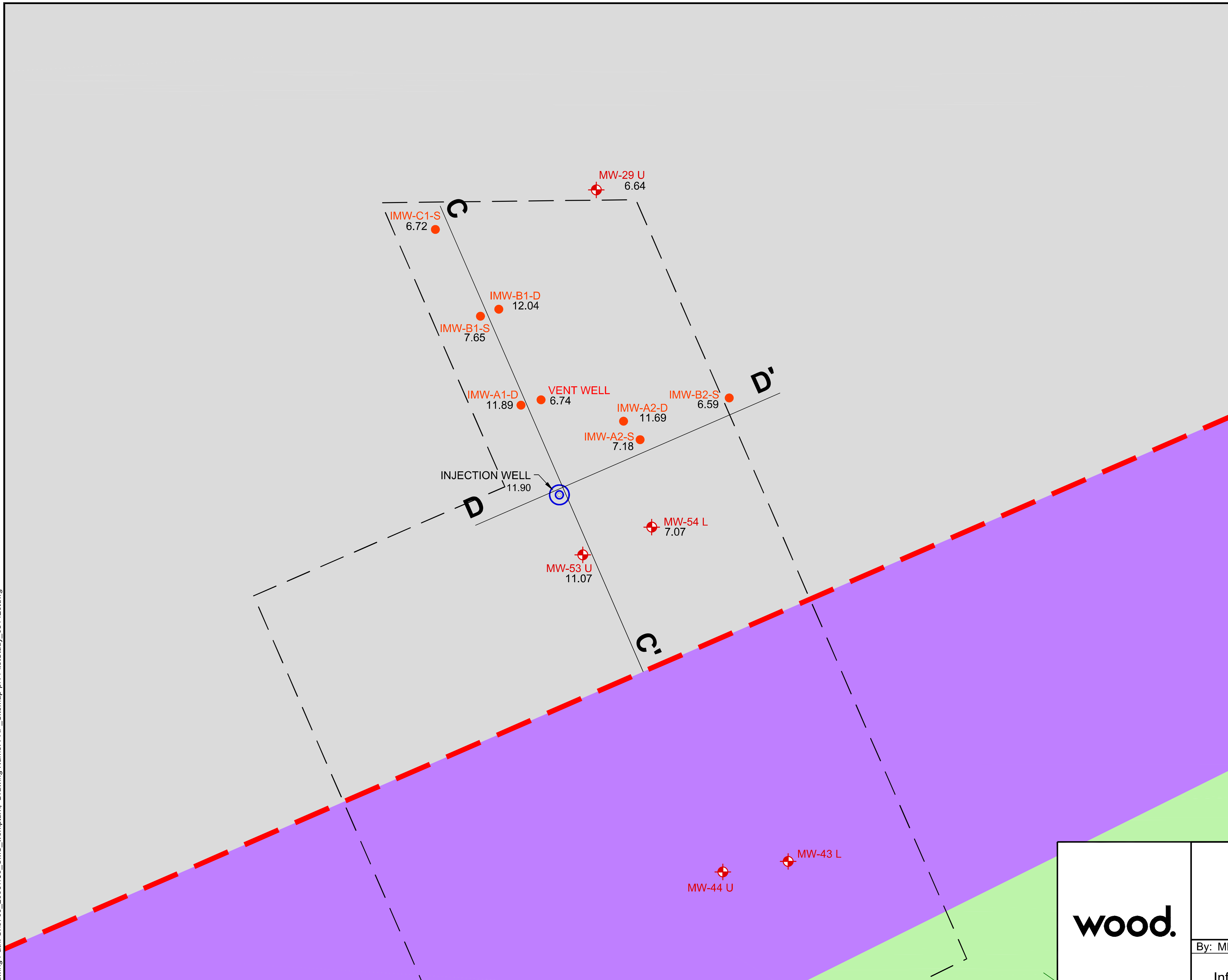
NOTE:

1. LITHOLOGY SHOWN TO APPROXIMATELY DELINEATE BETWEEN SOIL TYPES.
2. EXTENT OF HIGH pH CONTAMINATION SHOWN IS GENERALIZED TO REPRESENT THE APPROXIMATE EXTENT OF SOIL, SEDIMENT, AND GROUNDWATER WHERE pH IS GREATER THAN 8.5 AT THE SITE.
3. LOCATIONS OF CROSS SECTIONS ARE SHOWN ON FIGURE 1.

wood.

DUWAMISH AND SLIP 6 SHORELINE
CROSS SECTION pH CONTAMINATION SUMMARY
Former Rhone-Poulenc Site
Tukwila, Washington

| By: APS | Date: 05/15/20 | Project No. 08769 |
|---|---|---|
| Amec Foster Wheeler Environment & Infrastructure, Inc. | | Figure 3 |




## EXPLANATION

PROPERTY LINE

APPROXIMATE LOCATION OF BARRIER WALL

IMW-A1-D $CO_2$ INJECTION MONITORING WELL

MW-54 L 7.07 MONITORING WELL GROUNDWATER pH DURING BASELINE SAMPLING

INJECTION WELL

PILOT STUDY AREA

C —— C' LOCATIONS OF CROSS SECTIONS SHOWN ON FIGURES 4 AND 15-20

## MONITORING WELL NETWORK

U UPPER ZONE MONITORING POINT

L LOWER ZONE MONITORING POINT

-S SHALLOW MONITORING POINT

-D DEEP MONITORING POINT

## KEY

HCIM AREA

SHORELINE AREA

PAVED SHORELINE AREA

N

0 5 10

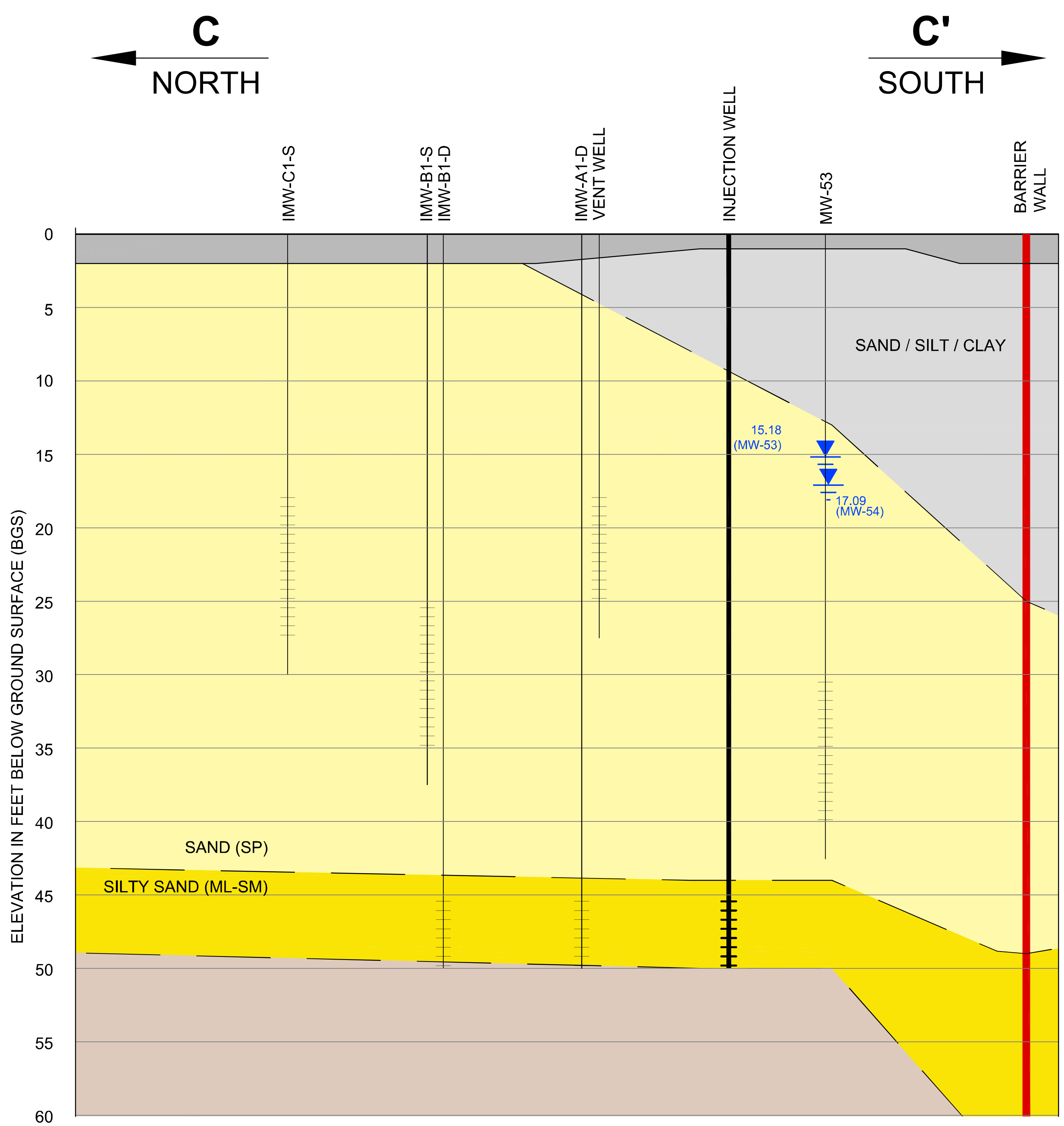
APPROXIMATE SCALE IN FEET

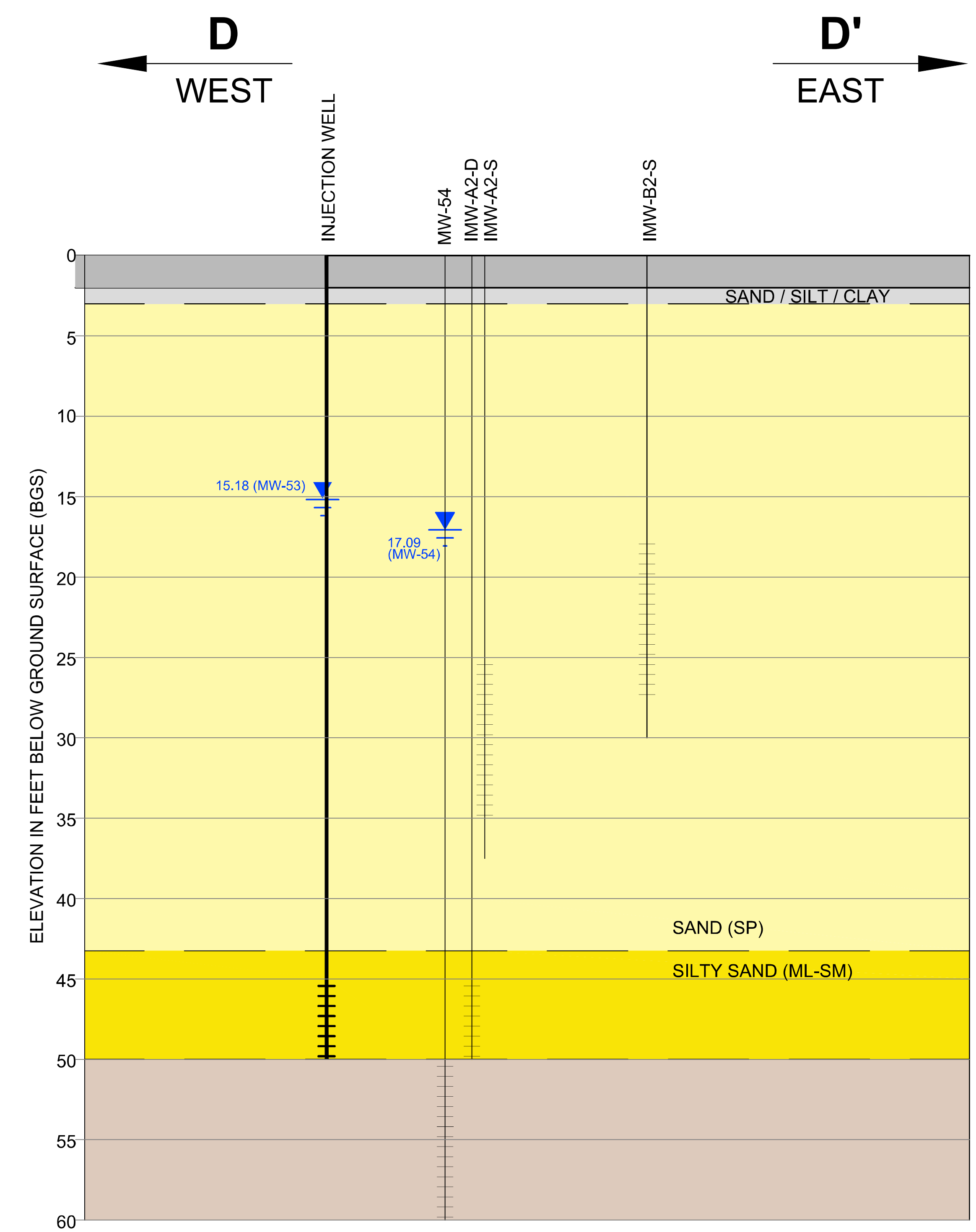
wood.

PILOT STUDY MONITORING AND INJECTION WELL LAYOUT
Former Rhone-Poulenc Site
Tukwila, Washington

| By: MDS | Date: 05/15/20 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 4 |

Plot Date: 05/15/20 - 8:55am, Plotted by: mike.stenberg
Drawing Path: S:\8769_2006\138_CMS_workplan\, Drawing Name: FRP_SiteMap-pH-PilotStudy_051420.dwg




LEGEND

- PAVEMENT
- SILT AQUITARD
- WATER TABLE INSIDE BARRIER WALL
- WELL SCREEN INTERVAL
- IMW INJECTION MONITORING WELL

KEY

- SAND / SILT / CLAY
- SAND (SP)
- SILTY SAND (ML-SM)

NOTES

A PLAN VIEW OF THE CROSS SECTIONS IS PRESENTED IN FIGURE 4.

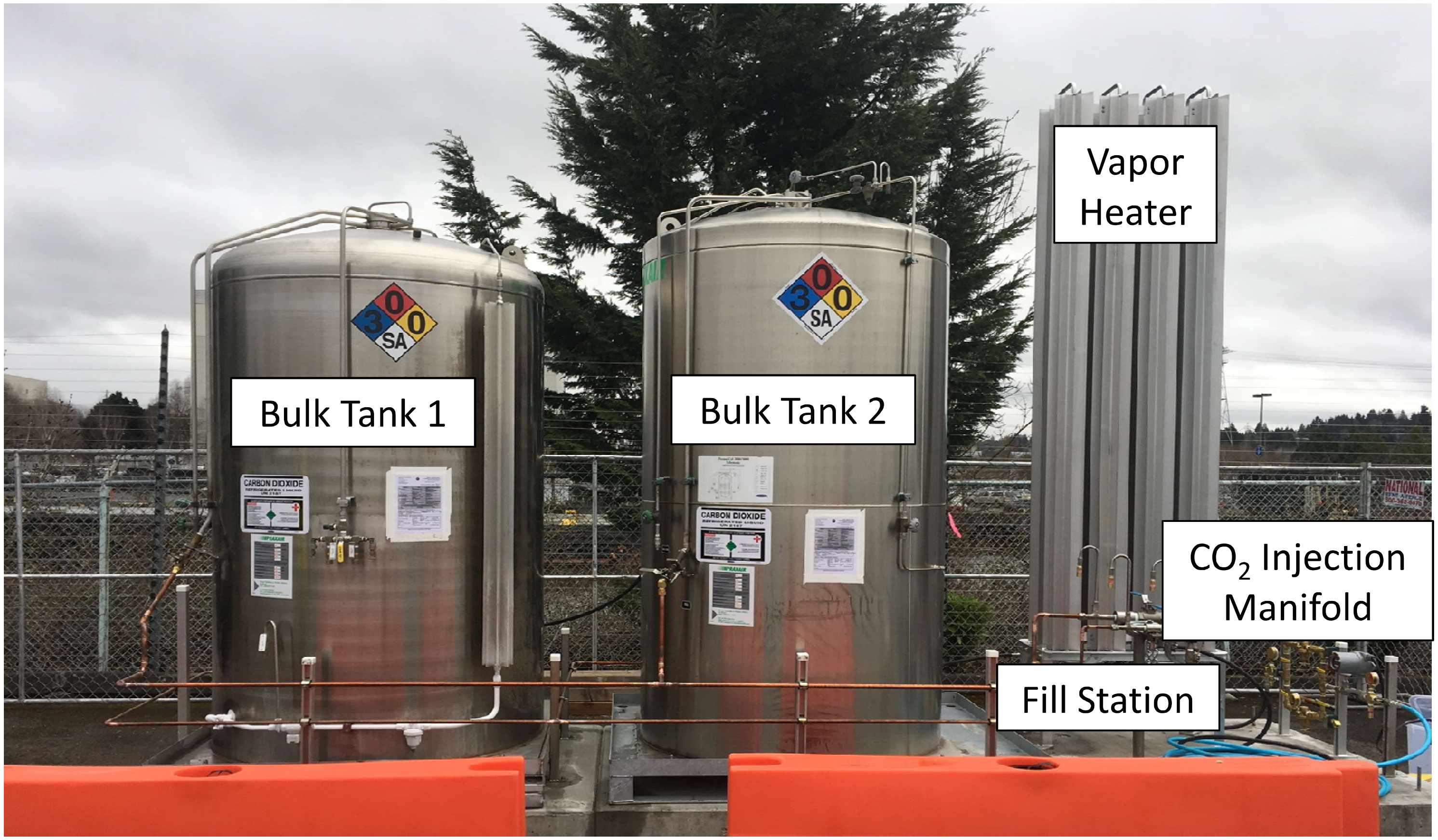
0 5 10
APPROXIMATE SCALE IN FEET

wood.

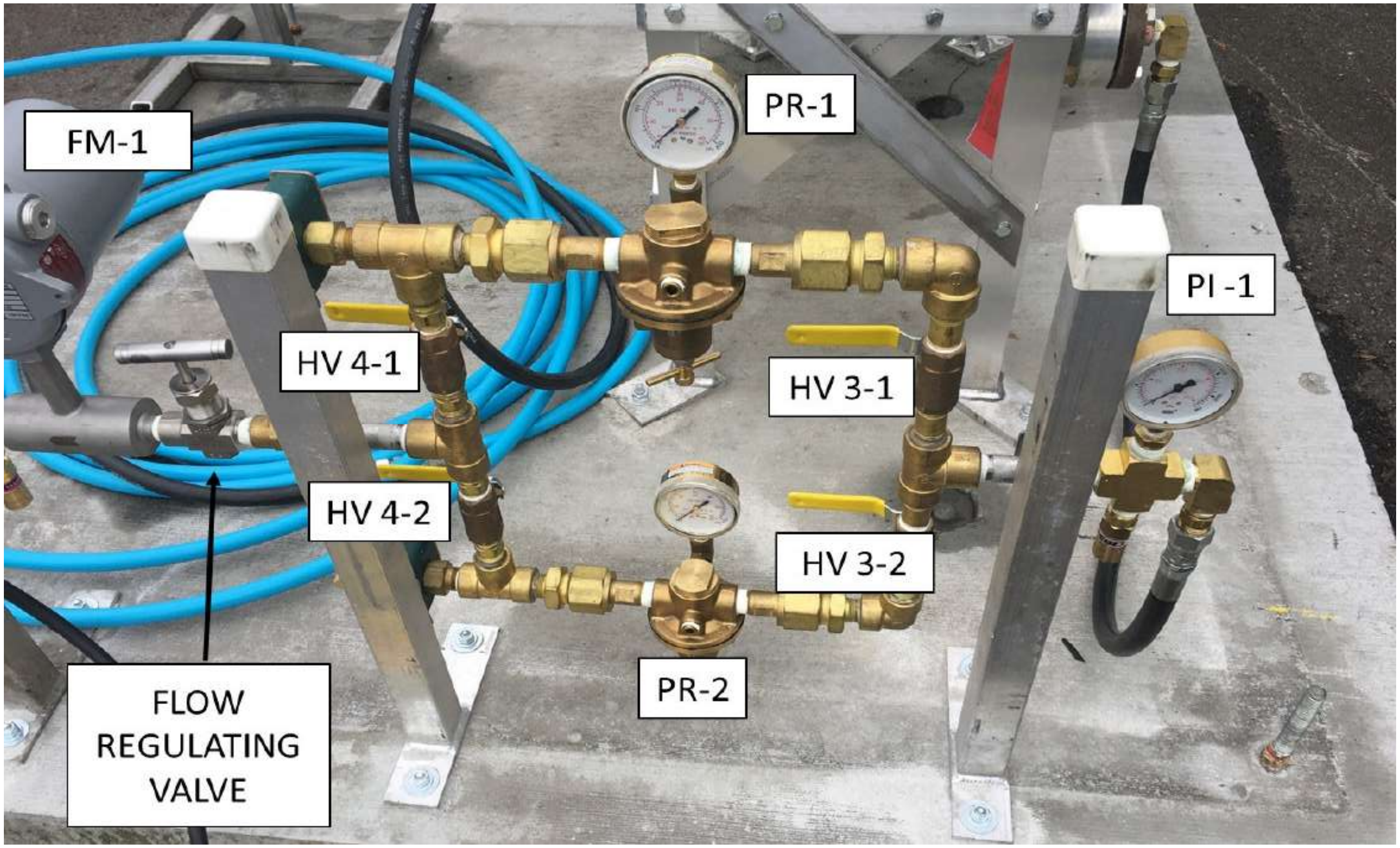
PILOT STUDY MONITORING AND INJECTION WELL PROFILE
Former Rhone-Poulenc Site
Tukwila, Washington

| By: MDS | Date: 05/15/20 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 5 |

Plot Date: 05/15/20 - 9:28am, Plotted by: mike.stenberg
Drawing Path: C:\Users\mike.stenberg\Desktop\Civil 3D Projects\Wood\FRP\FRP_SiteMap-pH-PilotStudy_043020_CrossSection - Standard\, Drawing Name: FRP_SiteMap-pH-PilotStudy_043020_CrossSection.dwg




| | |
|---|---|
| | $CO_2$ INJECTION SYSTEM - TANK AREA<br><br>Former Rhone-Poulenc Site<br>Tukwila, WA |
| By: WY<br>Project No.: 0087690050<br>Date: 04/21/2020 | Figure 6 |

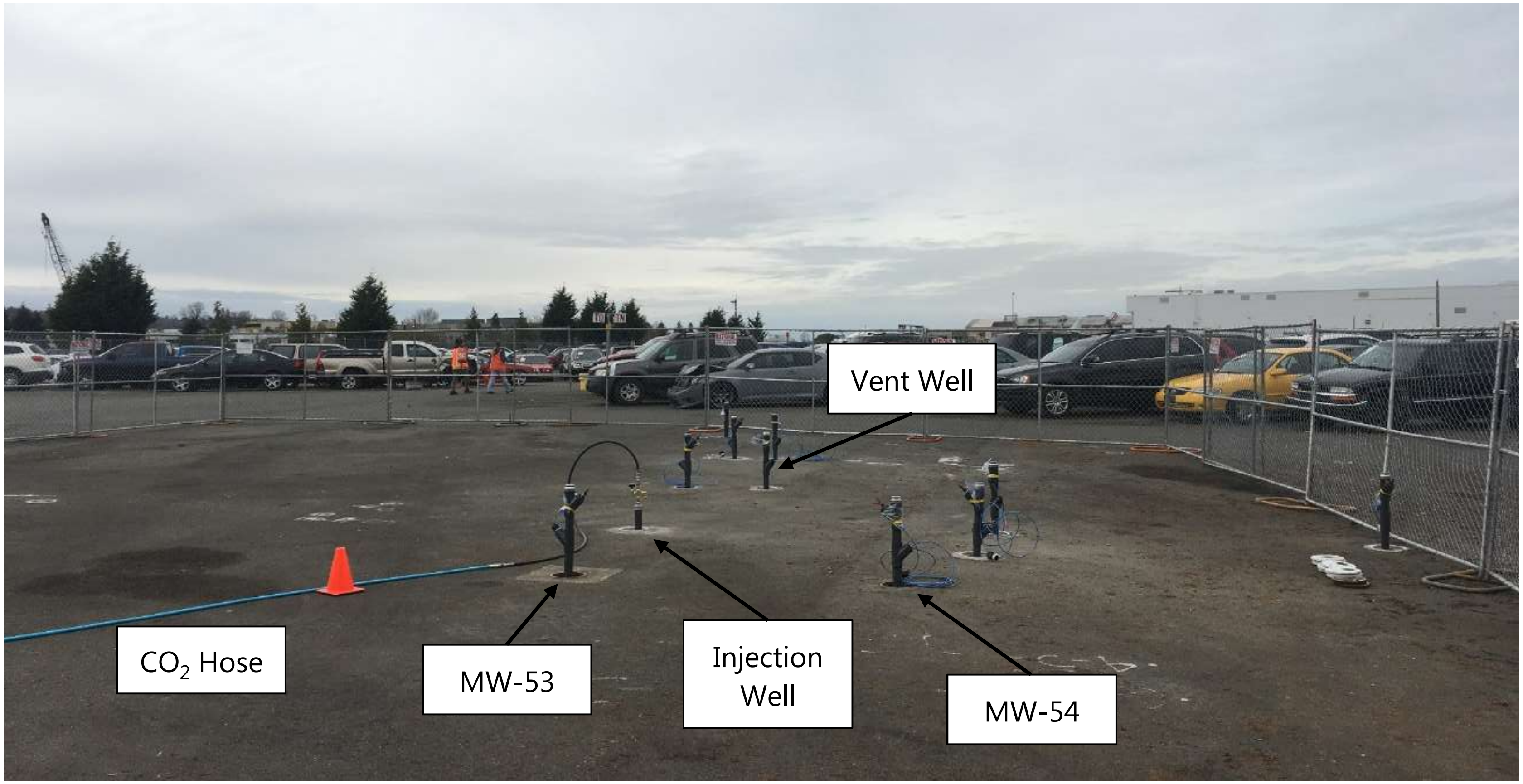



wood.

$CO_2$ INJECTION SYSTEM - VALVES AND CONTROLS

Former Rhone-Poulenc Site
Tukwila, WA

| | |
|---|---|
| By: WY | Figure 7 |
| Project No.: 0087690050 | |
| Date: 04/21/2020 | |




Notes

1. Unlabeled wells are observation wells.

wood.

$CO_2$ INJECTION SYSTEM - WELL LAYOUT

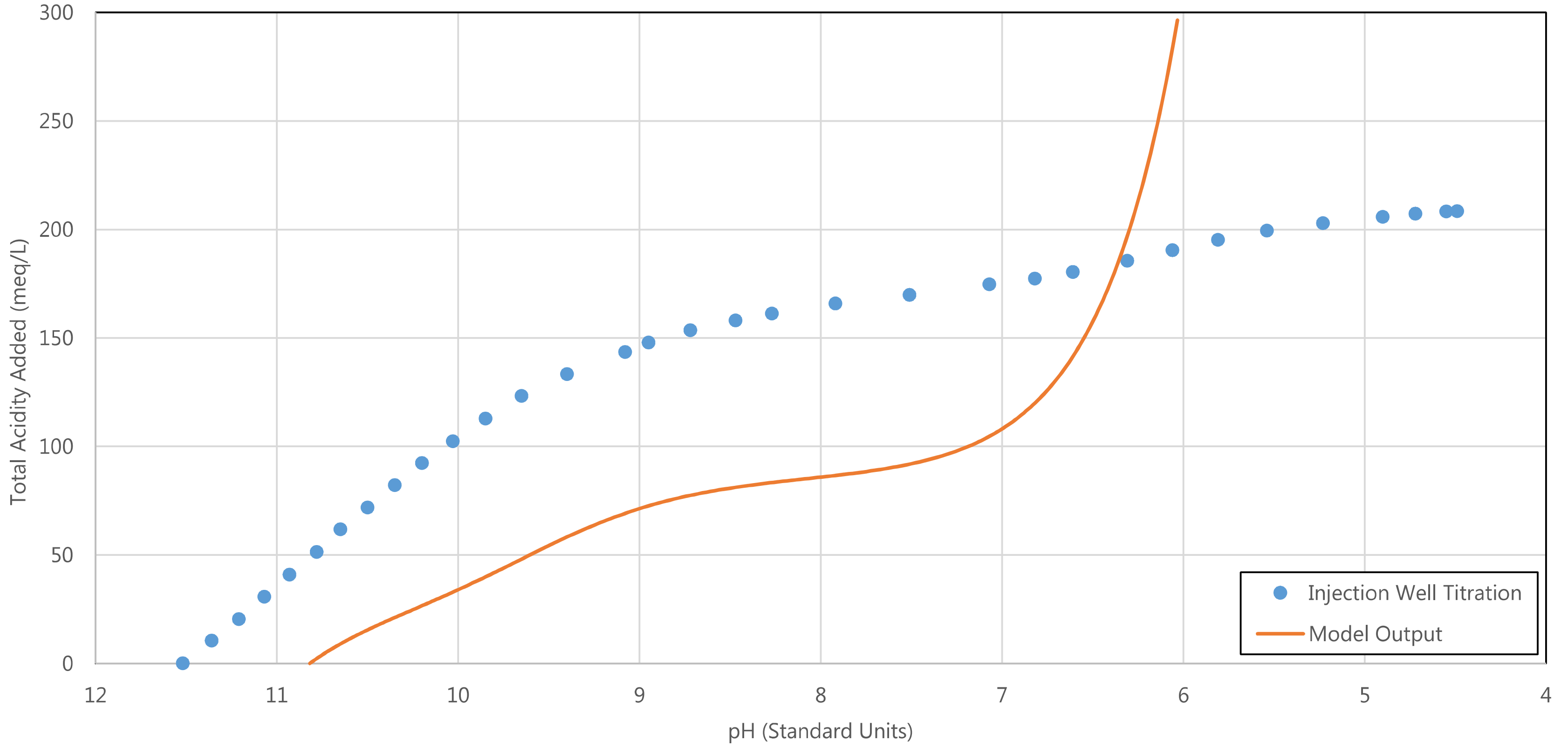
Former Rhone-Poulenc Site
Tukwila, WA

| | |
|---|---|
| By: WY | Figure 8 |
| Project No.: 0087690050 | |
| Date: 04/21/2020 | |


MONITORING WELL MANIFOLDS

Former Rhone-Poulenc Site
Tukwila, WA

| | |
|---|---|
| By: WY | Figure 9 |
| Project No.: 0087690050 | |
| Date: 04/21/2020 | |




<u>Abbreviations</u>

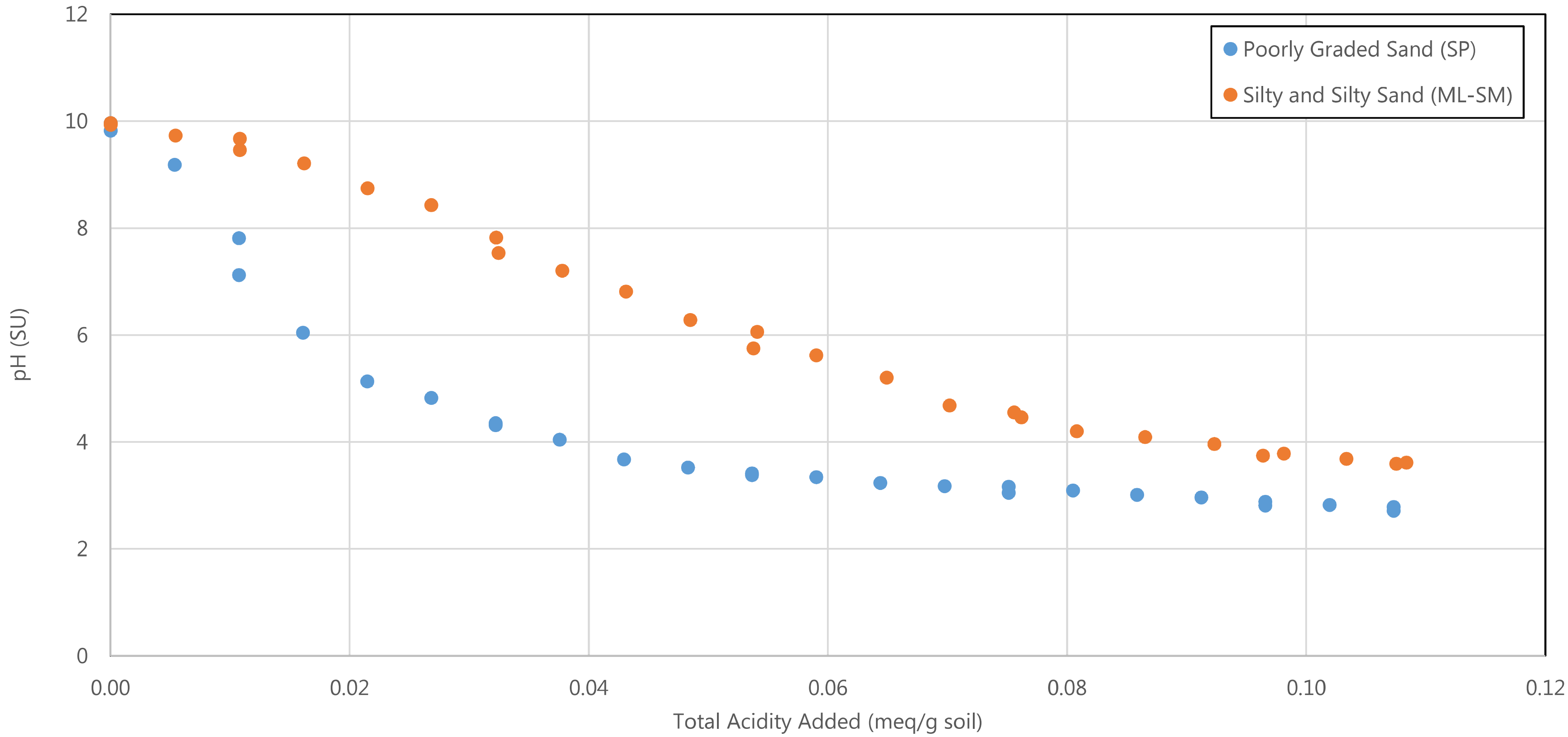
meq / L = milliequivalents per liter

wood.

INJECTION WELL GROUNDWATER TITRATION VERSUS MODEL

Former Rhone-Poulenc Site
Tukwila, WA

| | |
|---|---|
| By: WY | Figure 10 |
| Project No.: 0087690050 | |
| Date: 04/21/2020 | |




Notes

1. The acidity required to reduce the pH of the groundwater to 6.5 SU is 180.3 meq/L groundwater.

Abbreviations

g = gram

meq = milliequivalents

SU = standard pH units

PHASE 2 BUFFERING CAPACITY RESULTS

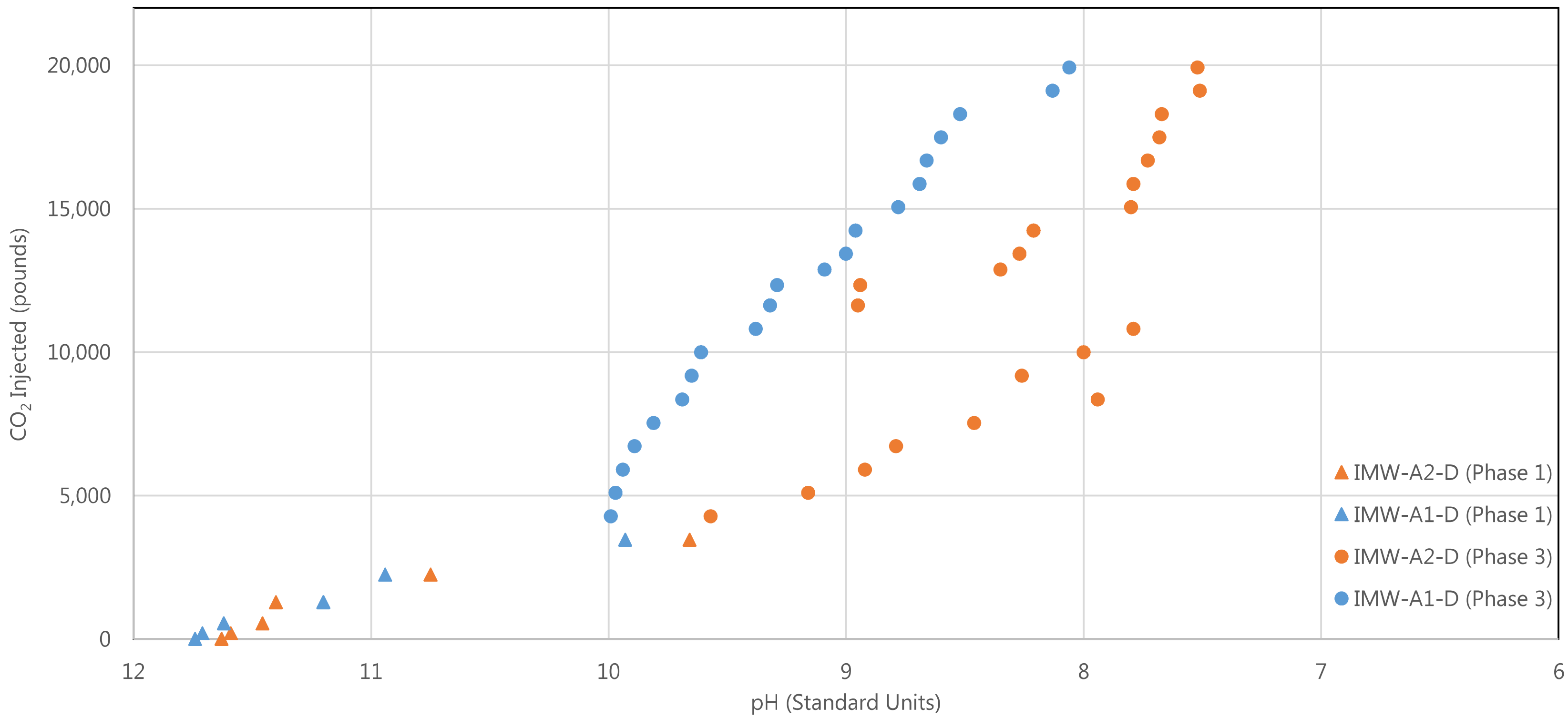
Former Rhone-Poulenc Site
Tukwila, WA

By: WY

Project No.: 0087690050

Date: 04/21/2020

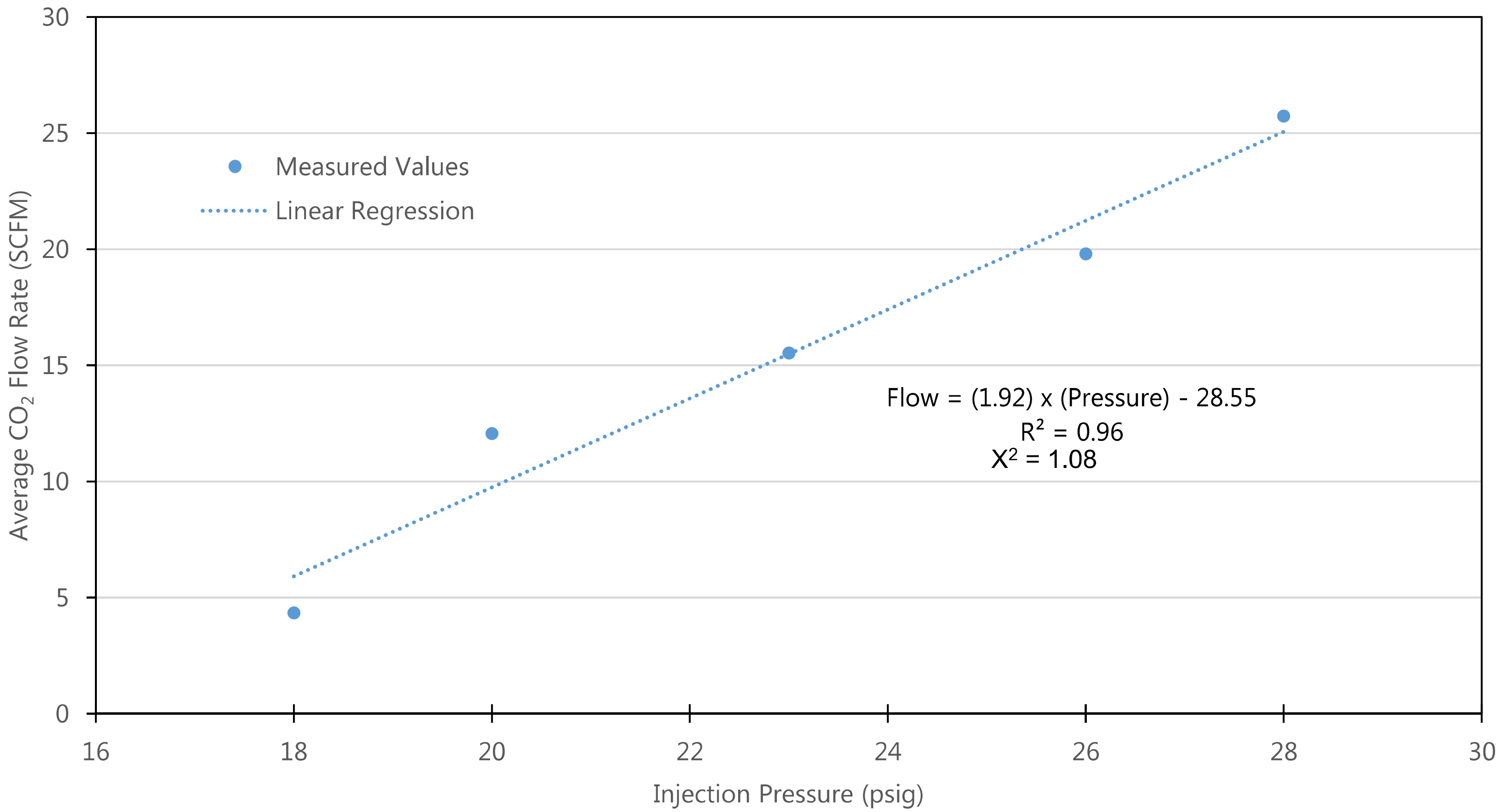
Figure 11




Notes

1. pH values represent transducer readings taken at 7:30 AM the day after an injection event.

| | | |
|---|---|---|
| wood. | PHASE 1 AND 3 $CO_2$ MASS INJECTED VERSUS pH<br><br>Former Rhone-Poulenc Site<br>Tukwila, WA | |
| | By: WY<br>Project No.: 0087690050<br>Date: 04/21/2020 | Figure 12 |




Notes

1. Pressure is based on manual readings of the pressure gauge on the injection wellhead manifold (PI-4).

2. Flow rate is calculated using changes in $CO_2$ level in each tank, recorded hourly, and the total duration of the injection event.

Abbreviations

psig = pounds per square inch (gauge)

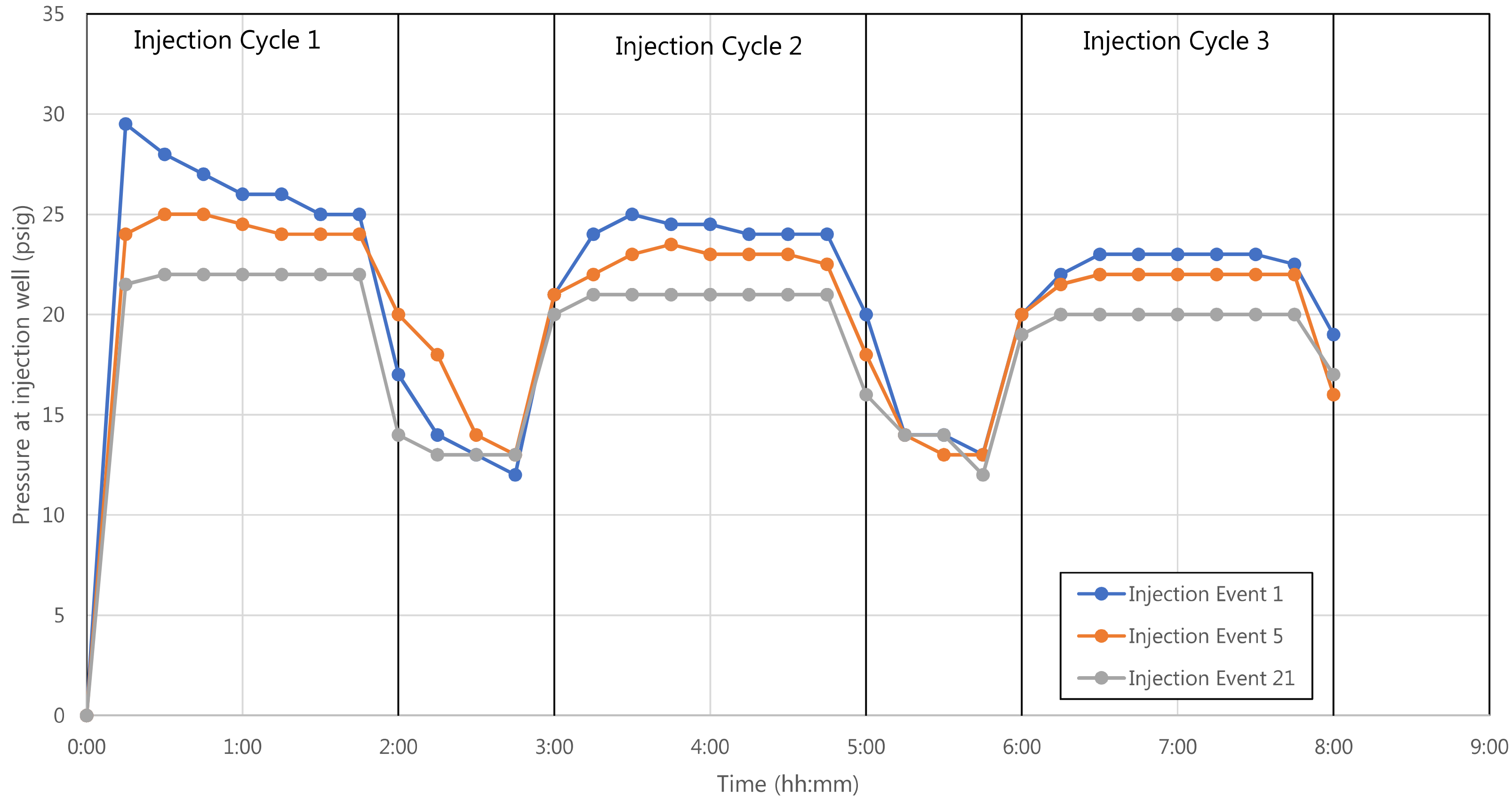
SCFM = standard cubic feet per minute

wood.

INJECTION PRESSURE AND $CO_2$ FLOW RATE
Former Rhone-Poulenc Site
Tukwila, WA

By: WMY
Project No.: 8769
Date 9/11/2018

Figure 13



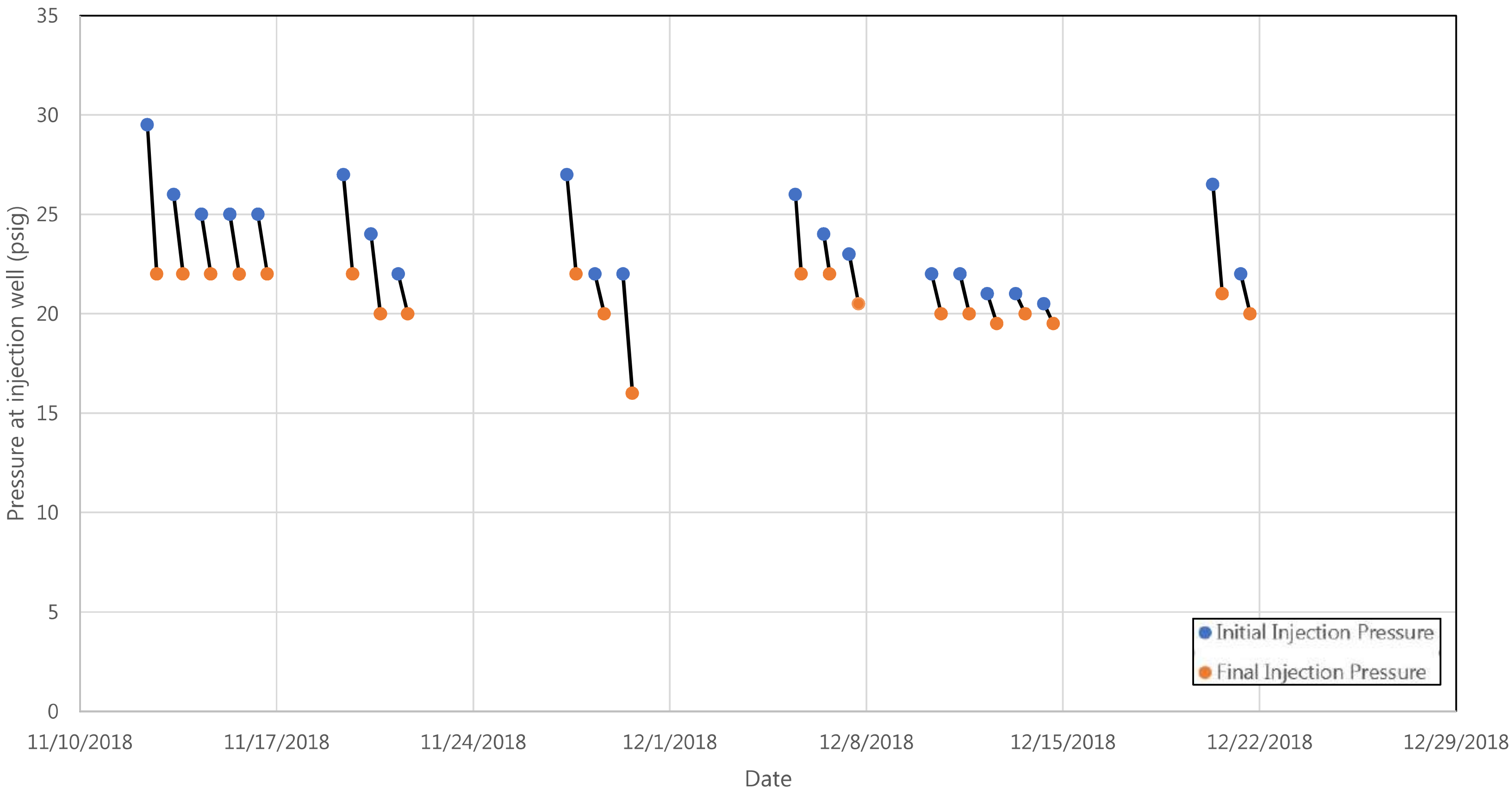

Notes

1. Pressure readings at 2:00, 5:00, and 8:00 were taken after $CO_2$ flow had stopped.
2. Pressure readings at 3:00 and 6:00 were taken after $CO^2$ flow had restarted.

Abbreviations

psig = pounds per square inch gauge

| | |
|---|---|
| wood. | PHASE 3 INJECTION PRESSURES<br><br>Former Rhone-Poulenc Site<br>Tukwila, WA |
| By: WY | Figure 14 |
| Project No.: 0087690050 | |
| Date: 04/21/2020 | |



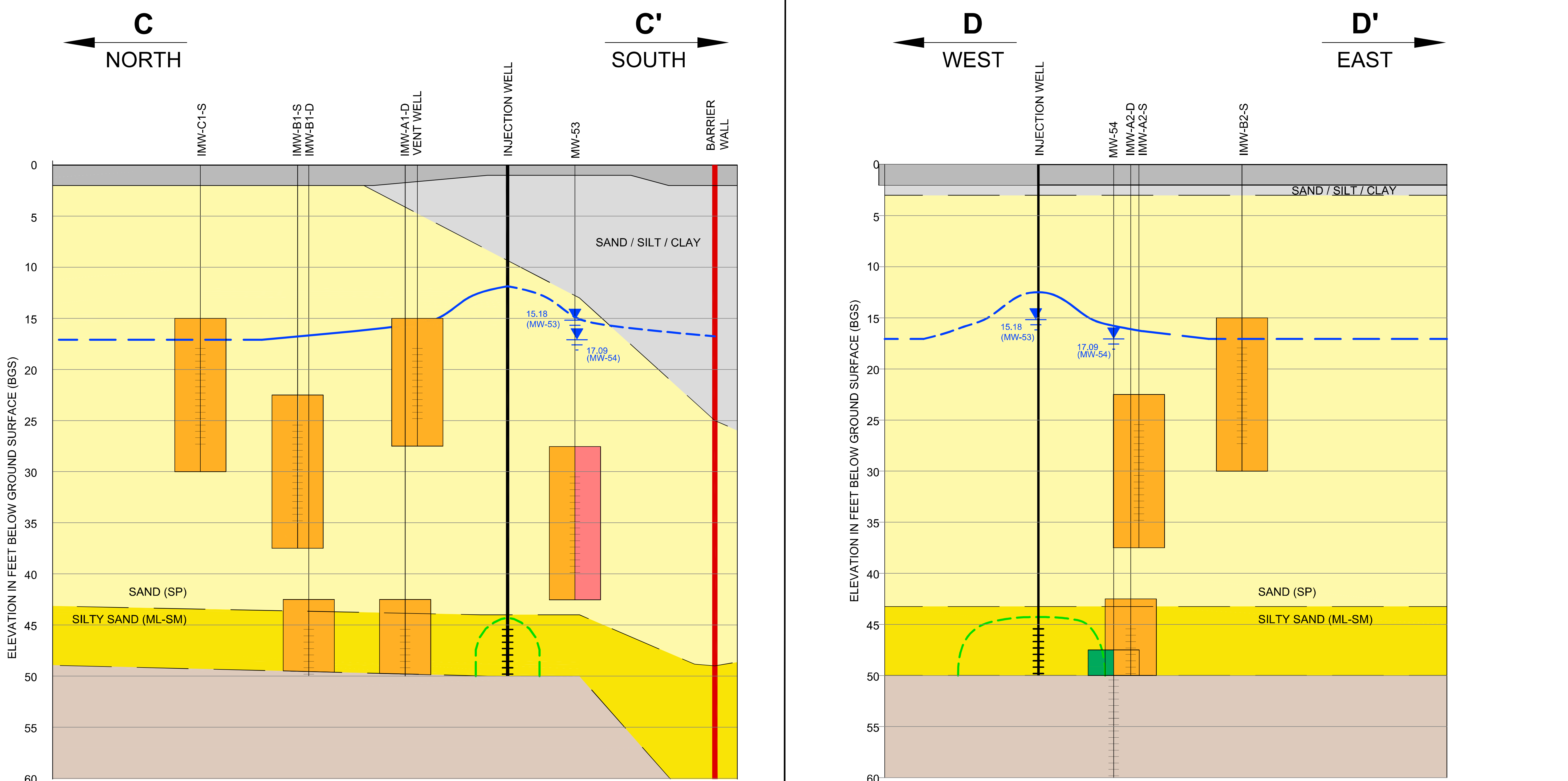

Notes

1. Initial pressure is the value recorded 15 minutes into the injection event.
2. Final pressure is the value 15 minutes prior to concluding the injection event.

Abbreviations

psgi = pounds per square inch (gauge)

| | | |
|---|---|---|
| wood. | PHASE 3 INITIAL AND FINAL INJECTION PRESSURES<br><br>Former Rhone-Poulenc Site<br>Tukwila, WA | |
| | By: WY | Figure 15 |
| | Project No.: 0087690050 | |
| | Date: 04/21/2020 | |




## LEGEND

- PAVEMENT
- SILT AQUITARD
- MEAN WATER TABLE ELEVATION PRIOR TO PILOT TESTING
- WELL SCREEN INTERVAL
- IMW INJECTION MONITORING WELL

## KEY

SHADING ON LEFT REFLECTS CHANGES IN DISSOLVED TIC

SHADING ON RIGHT REFLECTS CHANGES IN pH

- TIC CONCENTRATIONS DECREASED BY 22.5% OR MORE pH INCREASED BY 0.1 SU OR MORE
- pH & TIC CHANGES WERE NOT SIGNIFICANT
- TIC CONCENTRATIONS INCREASED BY 22.5% OR MORE pH DECREASED BY 0.1 SU OR MORE
- APPROXIMATE RADIUS OF INFLUENCE (TIC & pH)
- MAXIMUM WATER LEVEL RECORDED (LOWER AQUIFER ZONE DASHED WHEN INFERRED)

## NOTES

A PLAN VIEW OF THE CROSS SECTIONS IS PRESENTED IN FIGURE 4. THE WATER LEVEL SHOWN REPRESENTS THE MAXIMUM WATER LEVEL RECORDED IN THE LOWER AQUIFER ZONE DURING THE INJECTION EVENT.

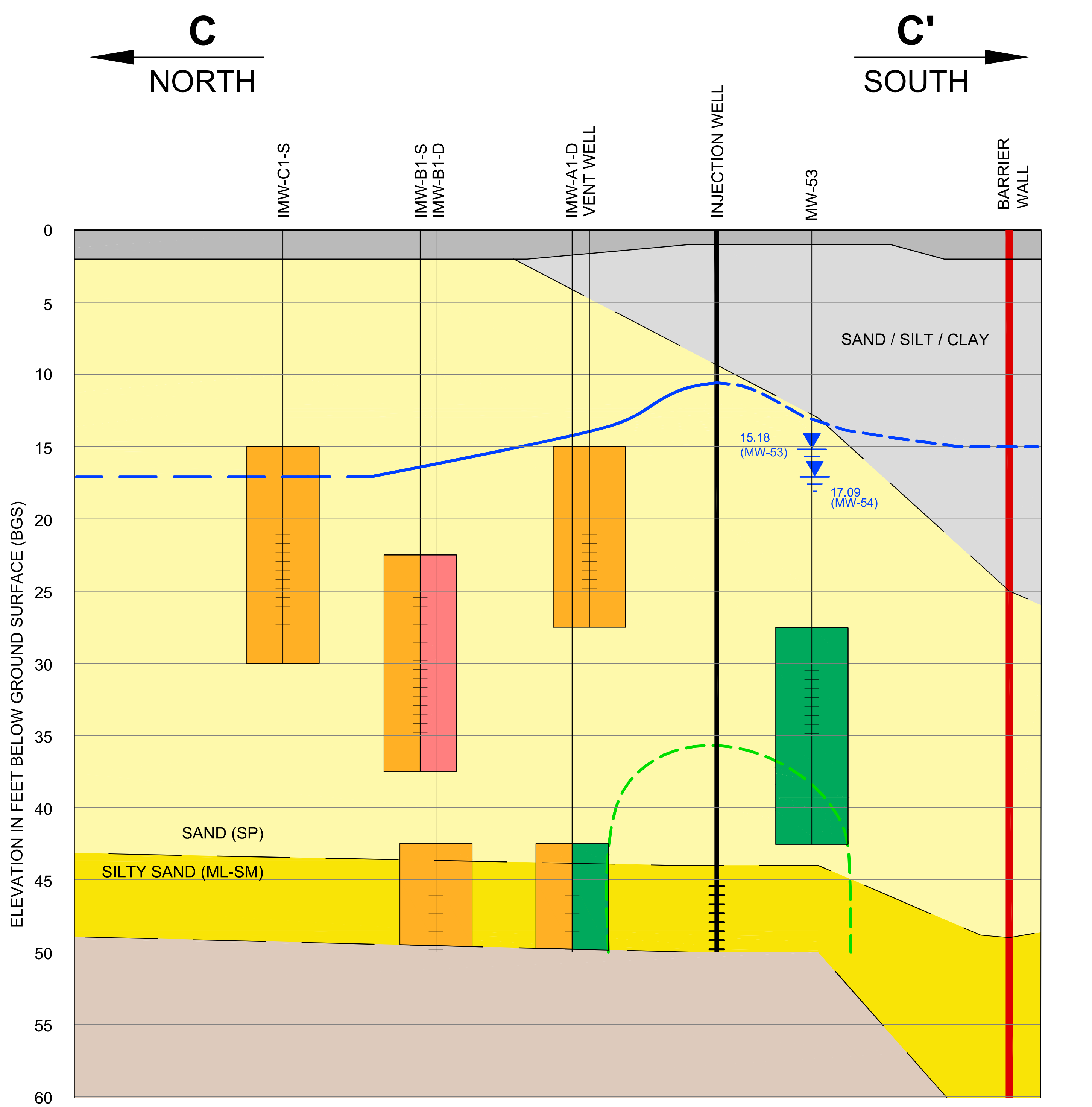
0 5 10
APPROXIMATE SCALE IN FEET

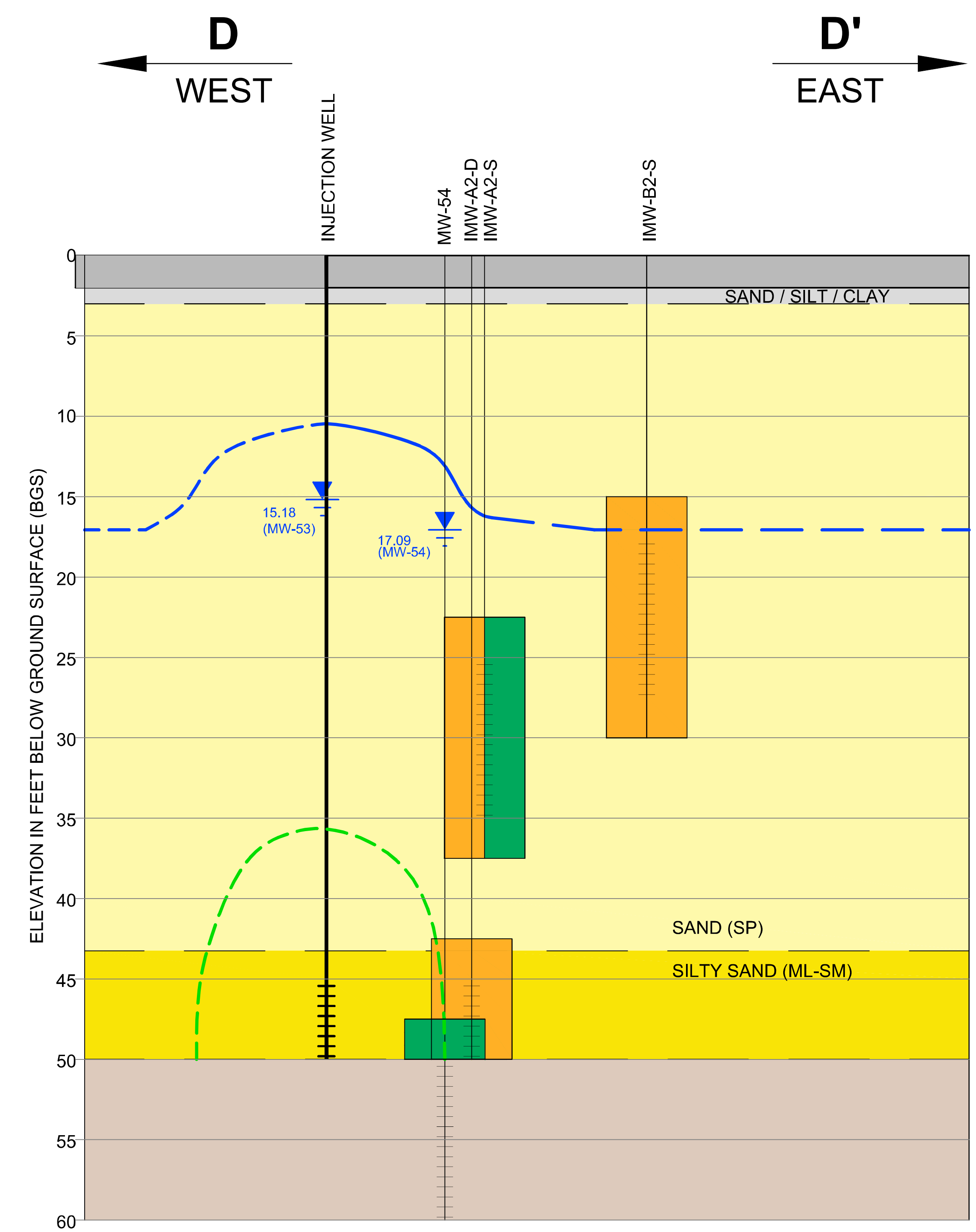
wood.

INJECTION 1 RADIUS OF INFLUENCE
Former Rhone-Poulenc Site
Tukwila, Washington

| By: MDS | Date: 05/15/20 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 16 |

Plot Date: 05/15/20 - 9:46am, Plotted by: mike.stenberg
Drawing Path: C:\Users\mike.stenberg\appdata\local\temp\AcPublish_508296\, Drawing Name: FRP_SiteMap-pH-PilotStudy_043020_CrossSection.dwg




## LEGEND

PAVEMENT

SILT AQUITARD

MEAN WATER TABLE ELEVATION PRIOR TO PILOT TESTING

WELL SCREEN INTERVAL

IMW INJECTION MONITORING WELL

## KEY

SHADING ON LEFT REFLECTS CHANGES IN DISSOLVED TIC

SHADING ON RIGHT REFLECTS CHANGES IN pH

TIC CONCENTRATIONS DECREASED BY 22.5% OR MORE pH INCREASED BY 0.1 SU OR MORE

pH & TIC CHANGES WERE NOT SIGNIFICANT

TIC CONCENTRATIONS INCREASED BY 22.5% OR MORE pH DECREASED BY 0.1 SU OR MORE

APPROXIMATE RADIUS OF INFLUENCE (TIC & pH)

MAXIMUM WATER LEVEL RECORDED (LOWER AQUIFER ZONE DASHED WHEN INFERRED)

## NOTES

A PLAN VIEW OF THE CROSS SECTIONS IS PRESENTED IN FIGURE 4. THE WATER LEVEL SHOWN REPRESENTS THE MAXIMUM WATER LEVEL RECORDED IN THE LOWER AQUIFER ZONE DURING THE INJECTION EVENT.

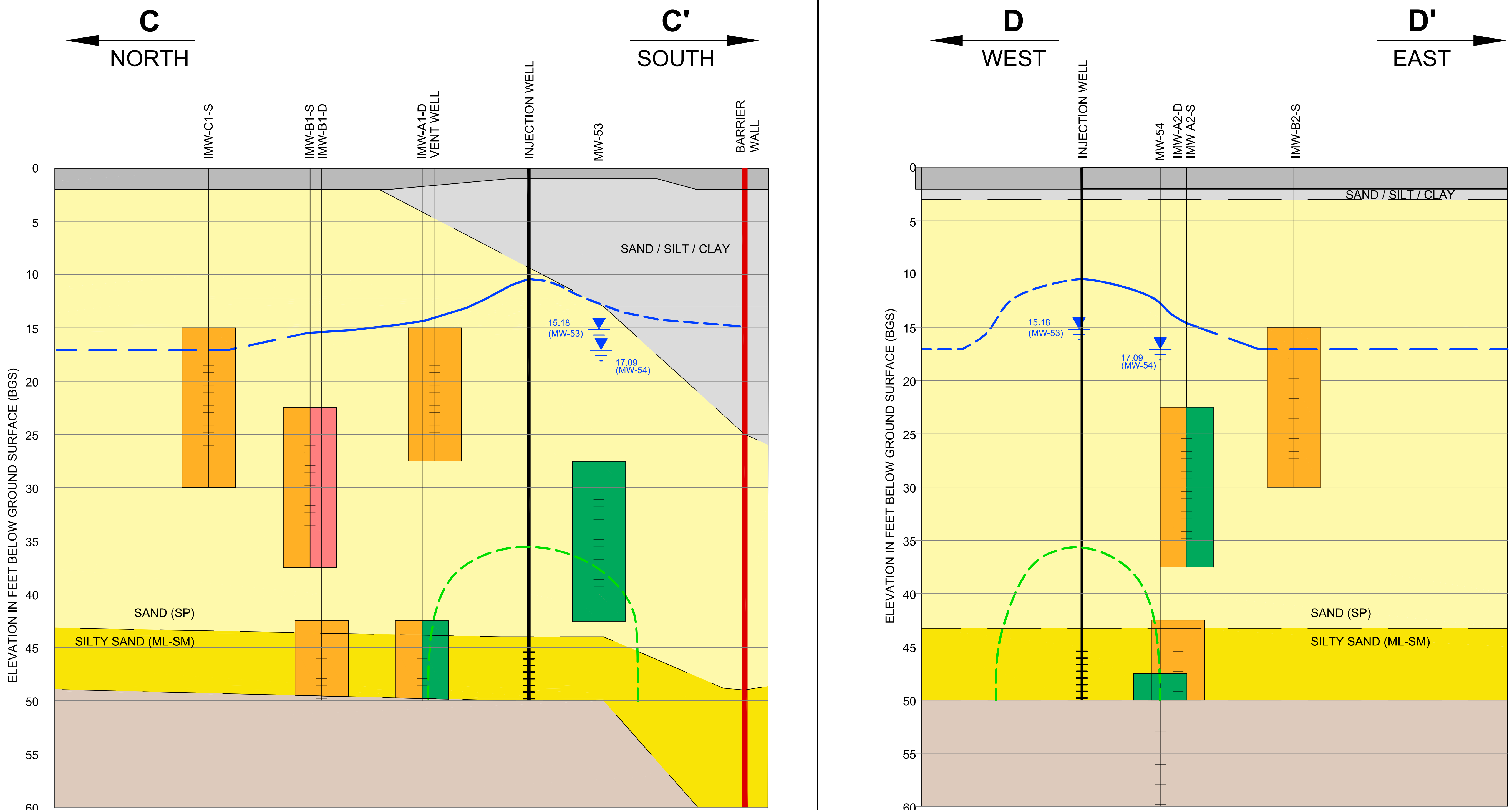
0 5 10
APPROXIMATE SCALE IN FEET

wood.

INJECTION 2 RADIUS OF INFLUENCE
Former Rhone-Poulenc Site
Tukwila, Washington

| By: APS | Date: 05/15/20 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 17 |

Plot Date: 05/15/20 - 9:46am, Plotted by: mike.stenberg
Drawing Path: C:\Users\mike.stenberg\appdata\local\temp\AcPublish_508296\, Drawing Name: FRP_SiteMap-pH-PilotStudy_043020_CrossSection.dwg




## LEGEND

PAVEMENT

SILT AQUITARD

MEAN WATER TABLE ELEVATION PRIOR TO PILOT TESTING.

WELL SCREEN INTERVAL

IMW INJECTION MONITORING WELL

## KEY

SHADING ON LEFT REFLECTS CHANGES IN DISSOLVED TIC

SHADING ON RIGHT REFLECTS CHANGES IN pH

TIC CONCENTRATIONS DECREASED BY 22.5% OR MORE pH INCREASED BY 0.1 SU OR MORE

pH & TIC CHANGES WERE NOT SIGNIFICANT

TIC CONCENTRATIONS INCREASED BY 22.5% OR MORE pH DECREASED BY 0.1 SU OR MORE

APPROXIMATE RADIUS OF INFLUENCE (TIC & pH)

MAXIMUM WATER LEVEL RECORDED (LOWER AQUIFER ZONE DASHED WHEN INFERRED)

## NOTES

A PLAN VIEW OF THE CROSS SECTIONS IS PRESENTED IN FIGURE 4. THE WATER LEVEL SHOWN REPRESENTS THE MAXIMUM WATER LEVEL RECORDED IN THE LOWER AQUIFER ZONE DURING THE INJECTION EVENT.

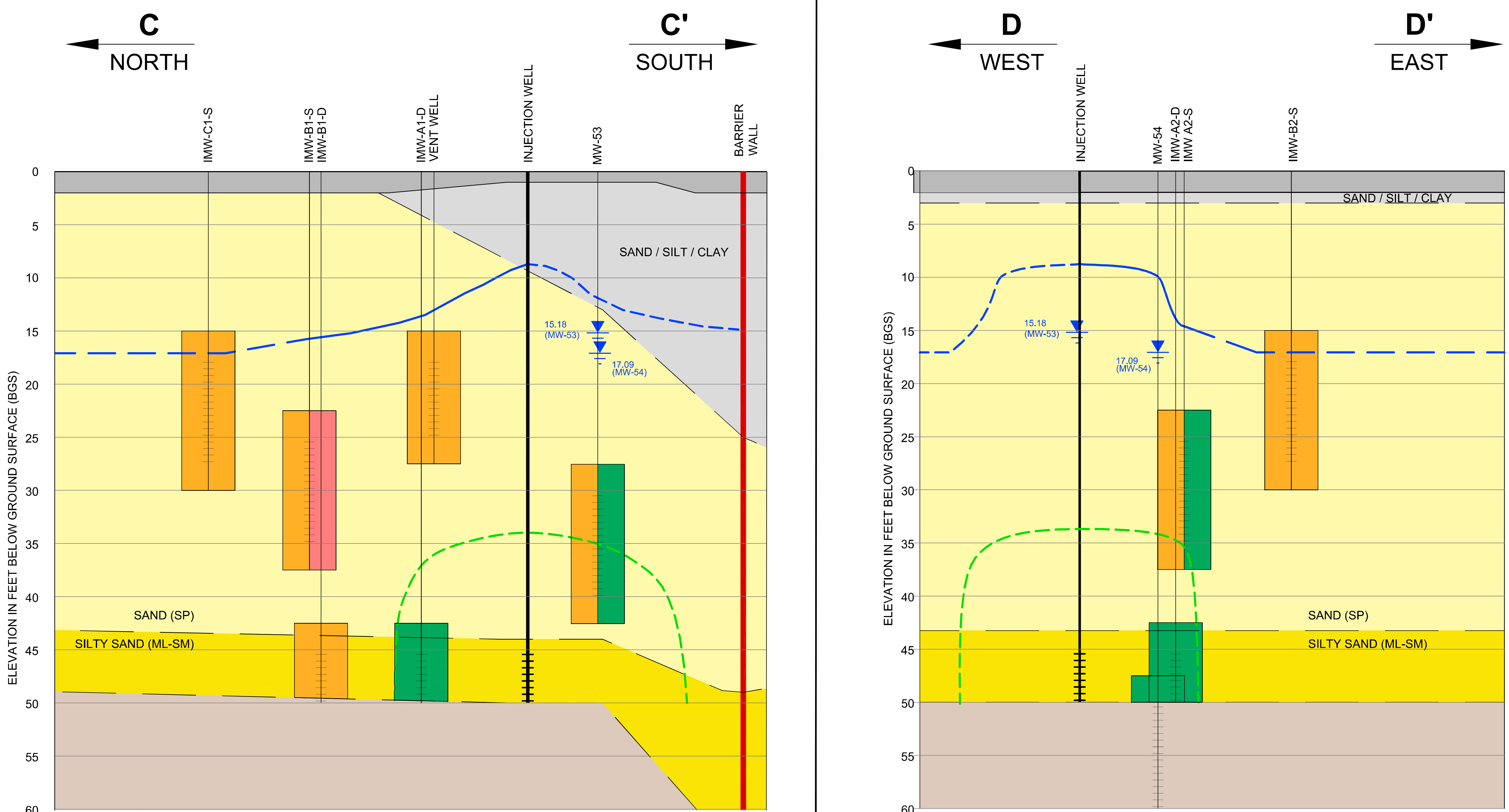
0 5 10
APPROXIMATE SCALE IN FEET

wood.

INJECTION 3 RADIUS OF INFLUENCE
Former Rhone-Poulenc Site
Tukwila, Washington

| By: APS | Date: 05/15/20 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 18 |

Plot Date: 05/15/20 - 9:47am, Plotted by: mike.stenberg
Drawing Path: C:\Users\mike.stenberg\appdata\local\temp\AcPublish_508296\, Drawing Name: FRP_SiteMap-pH-PilotStudy_043020_CrossSection.dwg




## LEGEND

- PAVEMENT
- SILT AQUITARD
- MEAN WATER TABLE ELEVATION PRIOR TO PILOT TESTING
- WELL SCREEN INTERVAL
- IMW INJECTION MONITORING WELL

## KEY

SHADING ON LEFT REFLECTS CHANGES IN DISSOLVED TIC

SHADING ON RIGHT REFLECTS CHANGES IN pH

- TIC CONCENTRATIONS DECREASED BY 22.5% OR MORE pH INCREASED BY 0.1 SU OR MORE
- pH & TIC CHANGES WERE NOT SIGNIFICANT
- TIC CONCENTRATIONS INCREASED BY 22.5% OR MORE pH DECREASED BY 0.1 SU OR MORE
- APPROXIMATE RADIUS OF INFLUENCE (TIC & pH)
- MAXIMUM WATER LEVEL RECORDED (LOWER AQUIFER ZONE DASHED WHEN INFERRED)

## NOTES

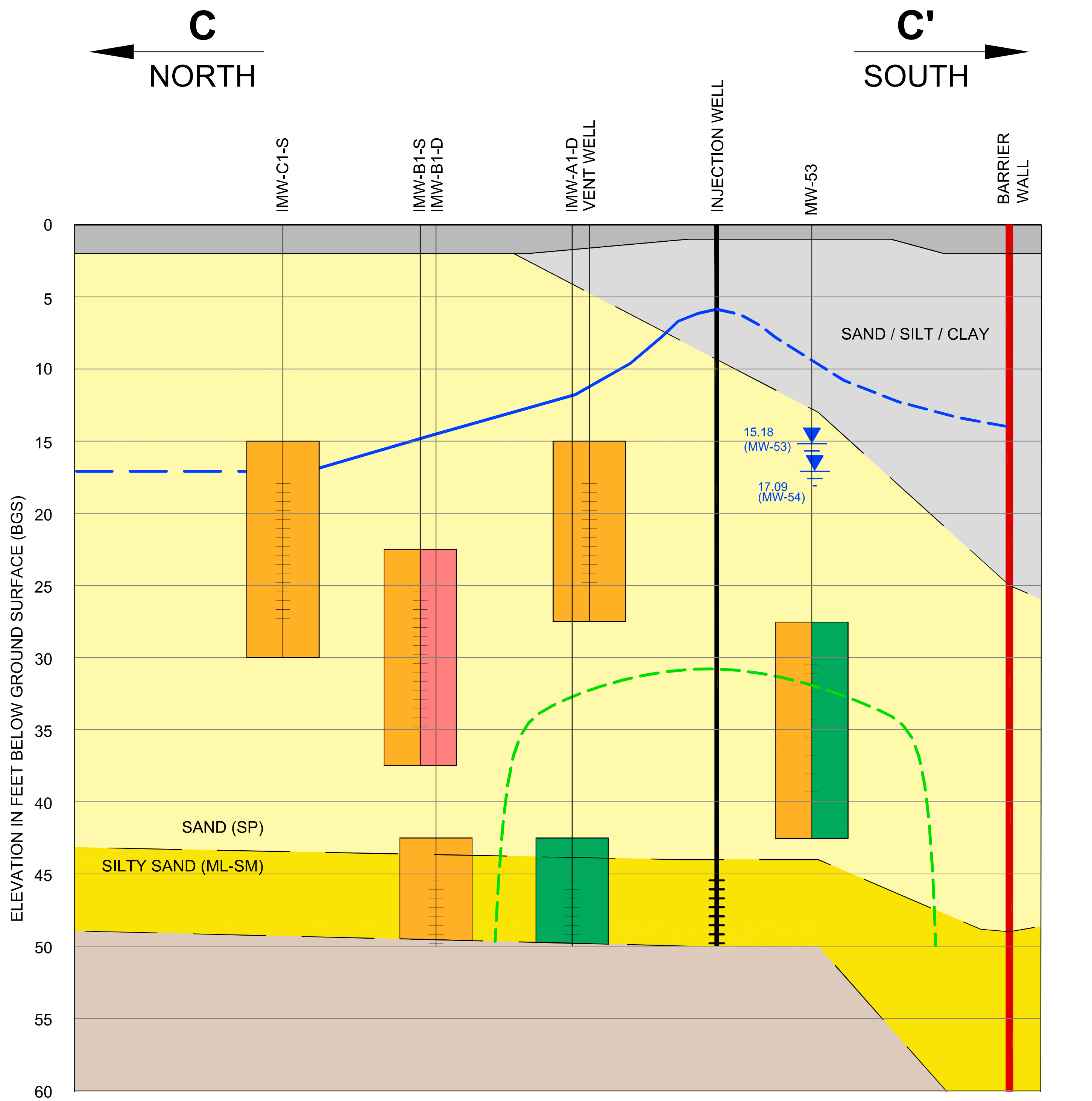
A PLAN VIEW OF THE CROSS SECTIONS IS PRESENTED IN FIGURE 4. THE WATER LEVEL SHOWN REPRESENTS THE MAXIMUM WATER LEVEL RECORDED IN THE LOWER AQUIFER ZONE DURING THE INJECTION EVENT.

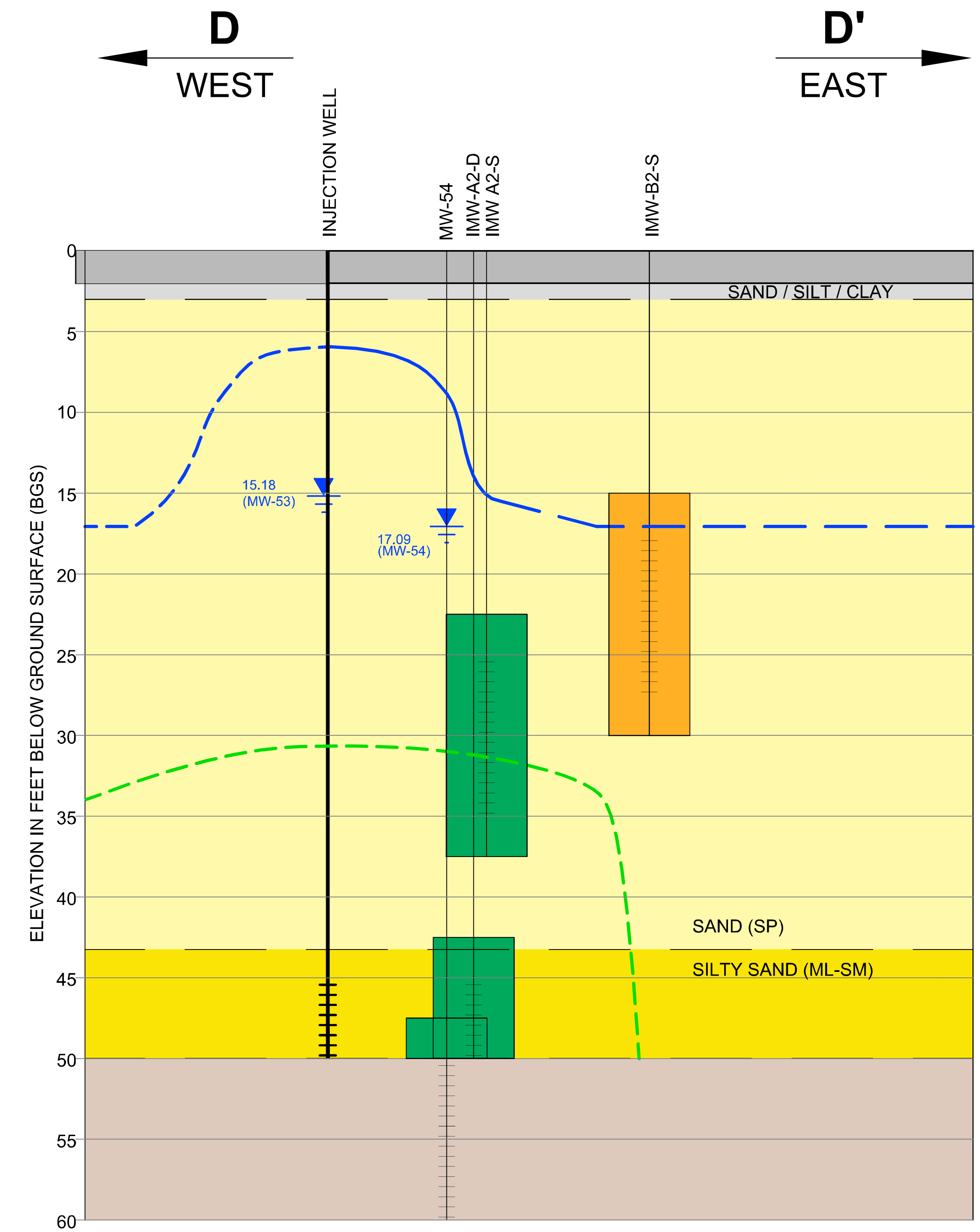
0 5 10
APPROXIMATE SCALE IN FEET

wood.

INJECTION 4 RADIUS OF INFLUENCE
Former Rhone-Poulenc Site
Tukwila, Washington

| By: APS | Date: 05/15/20 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 19 |




## LEGEND

PAVEMENT

SILT AQUITARD

MEAN WATER LEVEL PRIOR TO PILOT TESTING

WELL SCREEN INTERVAL

IMW INJECTION MONITORING WELL

## KEY

SHADING ON LEFT REFLECTS CHANGES IN DISSOLVED TIC

SHADING ON RIGHT REFLECTS CHANGES IN pH

TIC CONCENTRATIONS DECREASED BY 22.5% OR MORE pH INCREASED BY 0.1 SU OR MORE

pH & TIC CHANGES WERE NOT SIGNIFICANT

TIC CONCENTRATIONS INCREASED BY 22.5% OR MORE pH DECREASED BY 0.1 SU OR MORE

APPROXIMATE RADIUS OF INFLUENCE (TIC & pH)

MAXIMUM WATER LEVEL RECORDED (LOWER AQUIFER ZONE DASHED WHEN INFERRED)

## NOTES

A PLAN VIEW OF THE CROSS SECTIONS IS PRESENTED IN FIGURE 4. THE WATER LEVEL SHOWN REPRESENTS THE MAXIMUM WATER LEVEL RECORDED IN THE LOWER AQUIFER ZONE DURING THE INJECTION EVENT.

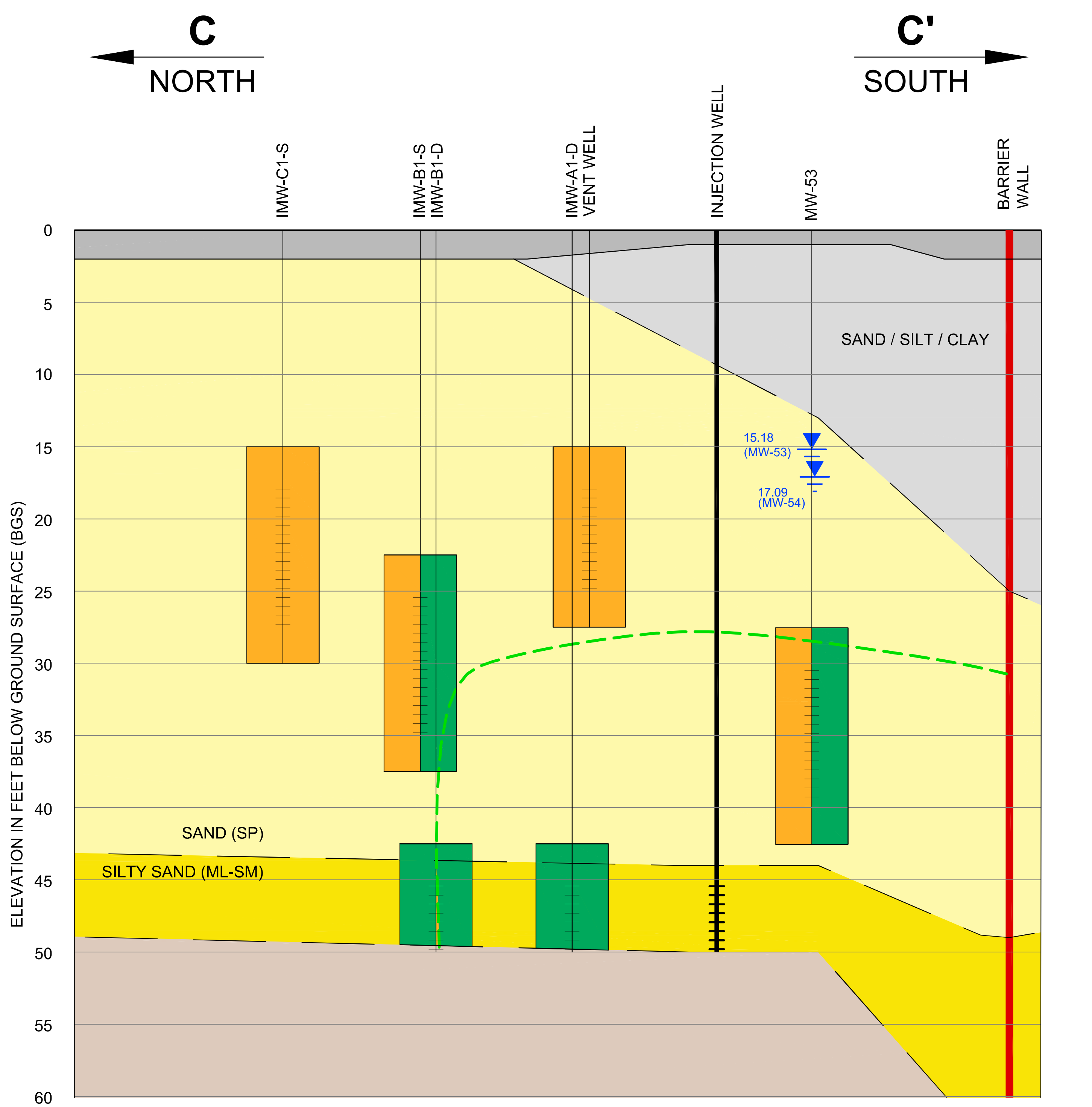
0 5 10

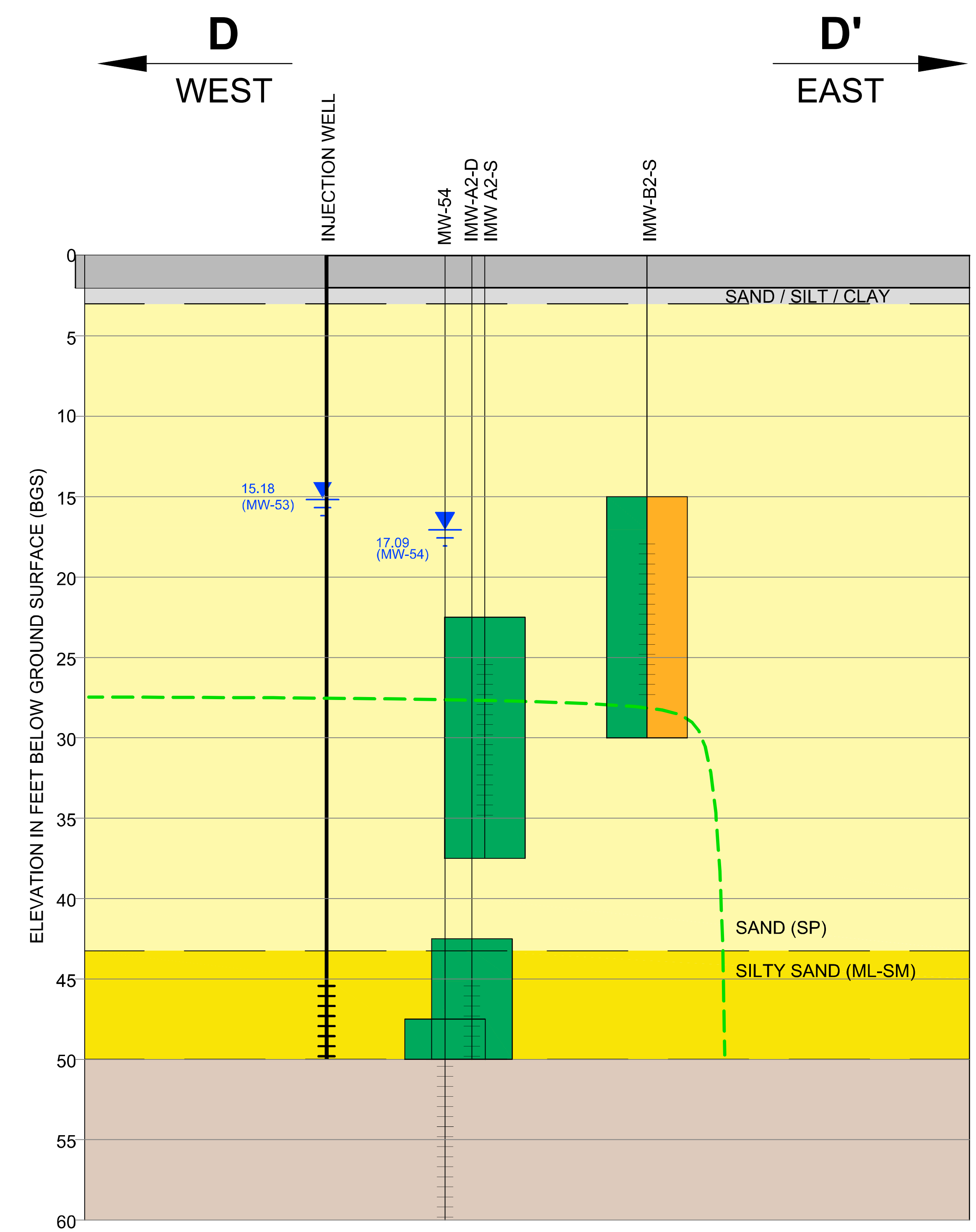
APPROXIMATE SCALE IN FEET

wood.

INJECTION 5 RADIUS OF INFLUENCE
Former Rhone-Poulenc Site
Tukwila, Washington

| By: APS | Date: 05/15/20 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 20 |




## LEGEND

- PAVEMENT
- SILT AQUITARD
- MEAN WATER TABLE ELEVATION PRIOR TO PILOT TESTING
- WELL SCREEN INTERVAL
- IMW INJECTION MONITORING WELL

## KEY

SHADING ON LEFT REFLECTS CHANGES IN DISSOLVED TIC

SHADING ON RIGHT REFLECTS CHANGES IN pH

MEAN WATER TABLE ELEVATION PRIOR TO PILOT TESTING.

- TIC CONCENTRATIONS DECREASED BY 22.5% OR MORE pH INCREASED BY 0.1 SU OR MORE
- pH & TIC CHANGES WERE NOT SIGNIFICANT
- TIC CONCENTRATIONS INCREASED BY 22.5% OR MORE pH DECREASED BY 0.1 SU OR MORE
- APPROXIMATE RADIUS OF INFLUENCE (TIC & pH)

## NOTES

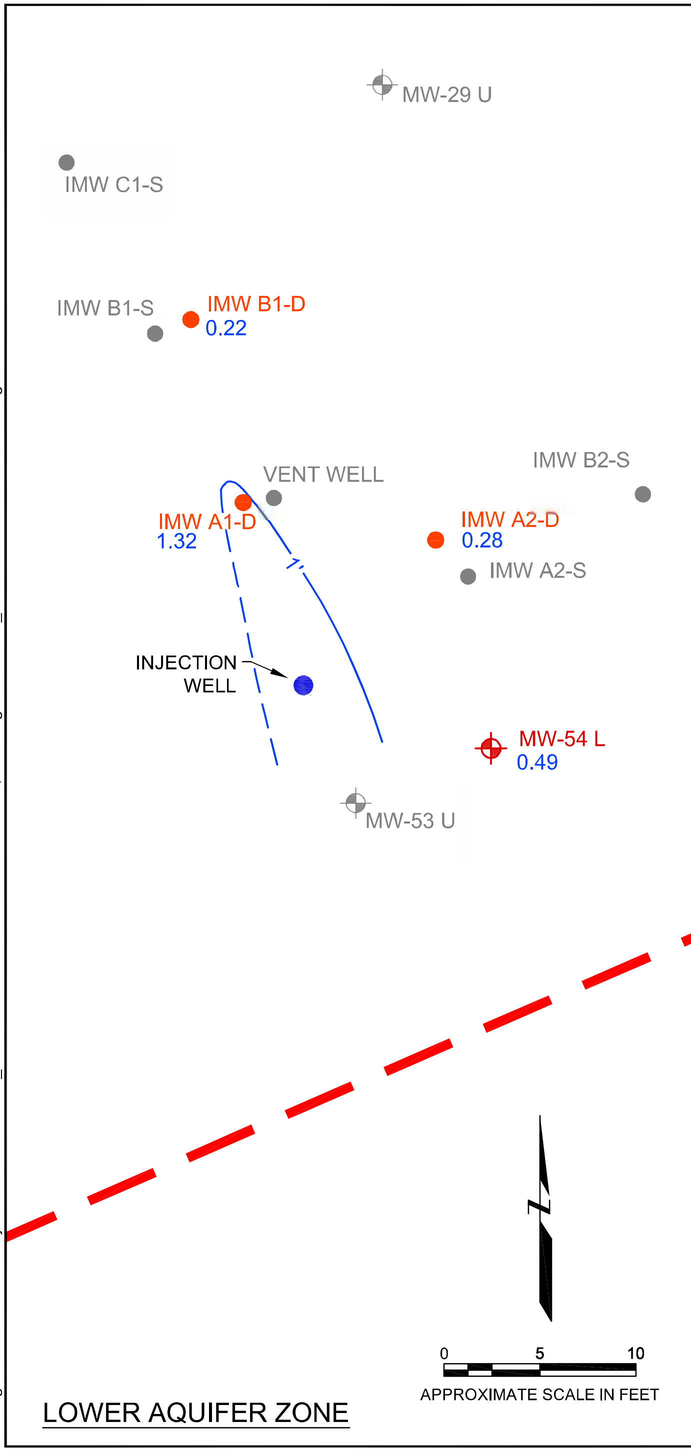
A PLAN VIEW OF THE CROSS SECTIONS IS PRESENTED IN FIGURE 4. THE WATER LEVEL SHOWN REPRESENTS THE MAXIMUM WATER LEVEL RECORDED IN THE LOWER AQUIFER ZONE DURING THE INJECTION EVENT.

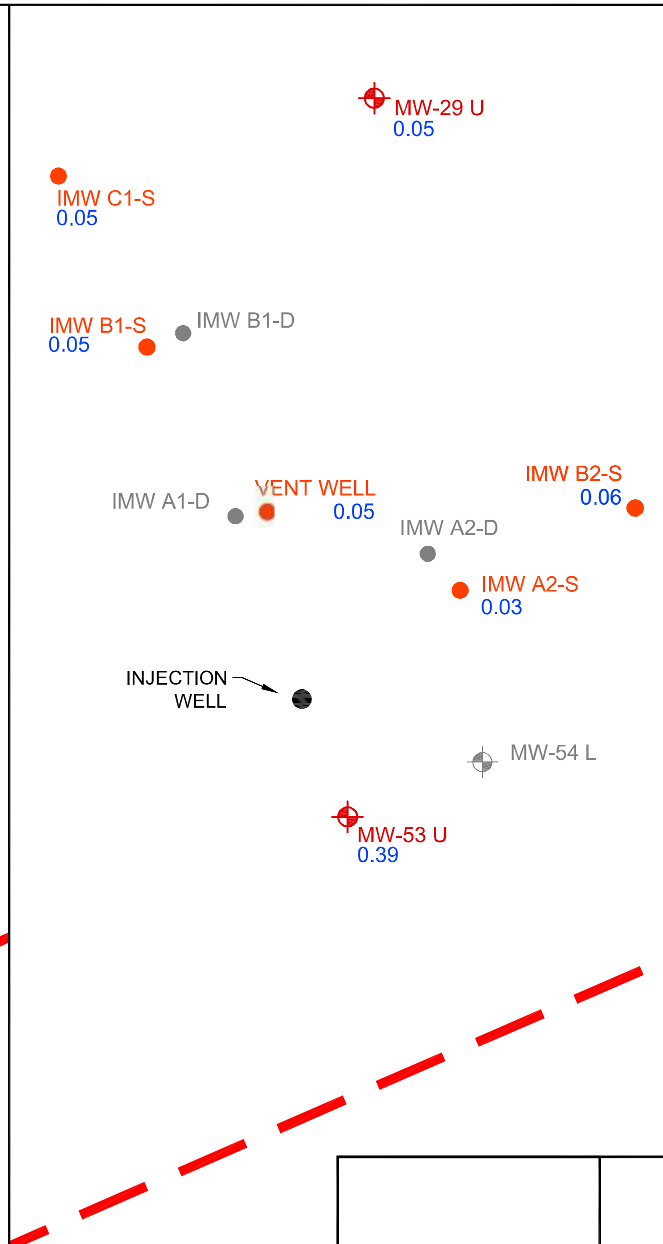
0 5 10
APPROXIMATE SCALE IN FEET

wood.

PHASE 3 RADIUS OF INFLUENCE
Former Rhone-Poulenc Site
Tukwila, Washington

| By: APS | Date: 05/15/20 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 21 |




## EXPLANATION

APPROXIMATE LOCATION OF BARRIER WALL

IMW A1 — $CO_2$ INJECTION MONITORING WELL

MW-29 U — MONITORING WELL

0.05 — MAXIMUM CHANGE IN WATER LEVEL RECORDED

1' — APPROXIMATE CHANGE IN GROUNDWATER ELEVATION (DASHED WHERE INFERRED)

## MONITORING WELL NETWORK

U — UPPER ZONE MONITORING POINT

L — LOWER ZONE MONITORING POINT

-S — SHALLOW MONITORING POINT

-D — DEEP MONITORING POINT

## NOTE

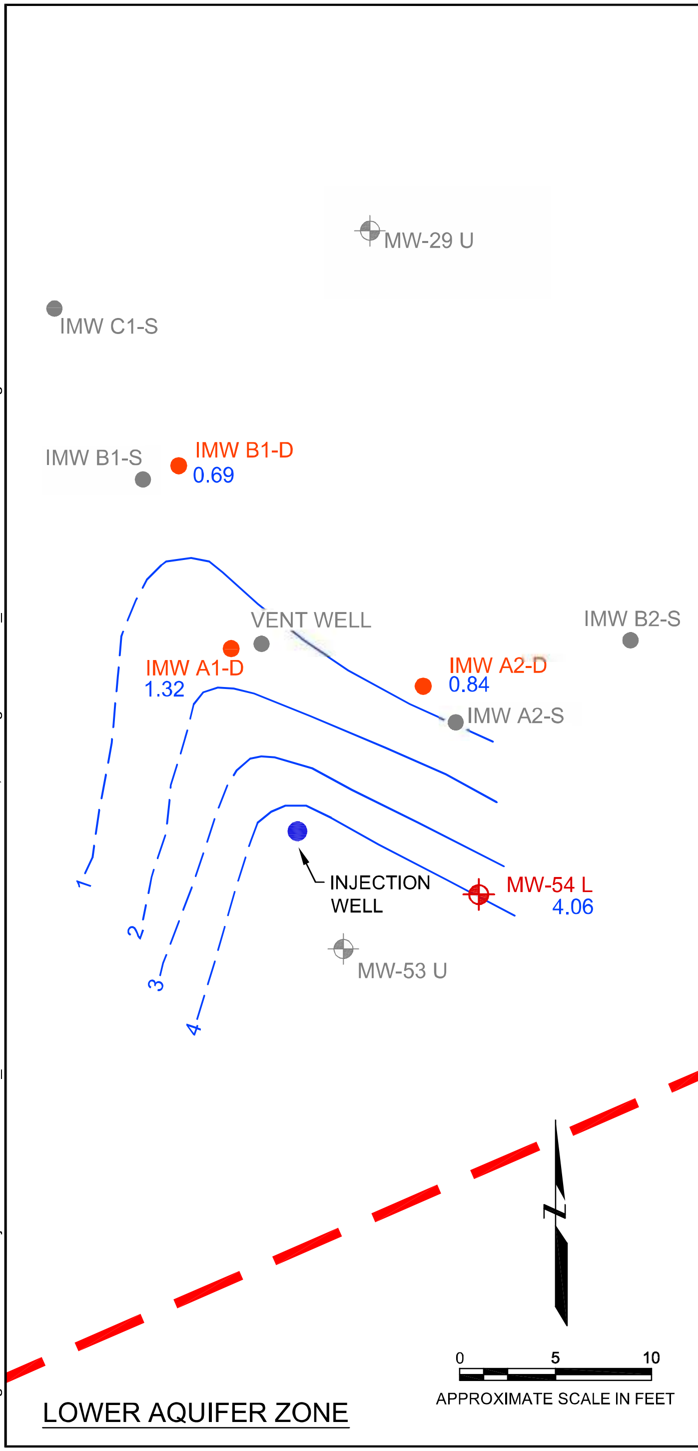
THE VALUES SHOWN ARE THE INCREASE FROM THE "30 MINUTE AVERAGE WATER LEVEL MEASURED PRIOR TO THE INJECTION EVENT."
WATER LEVEL INCREASES ARE MEASURED IN FEET.
THE VALUES SHOWN REPRESENT THE MAXIMUM WATER LEVEL RECORDED DURING THE INJECTION EVENT.
WELLS IN GREY WERE NOT USED WHEN DRAWING GROUNDWATER CONTOURS.

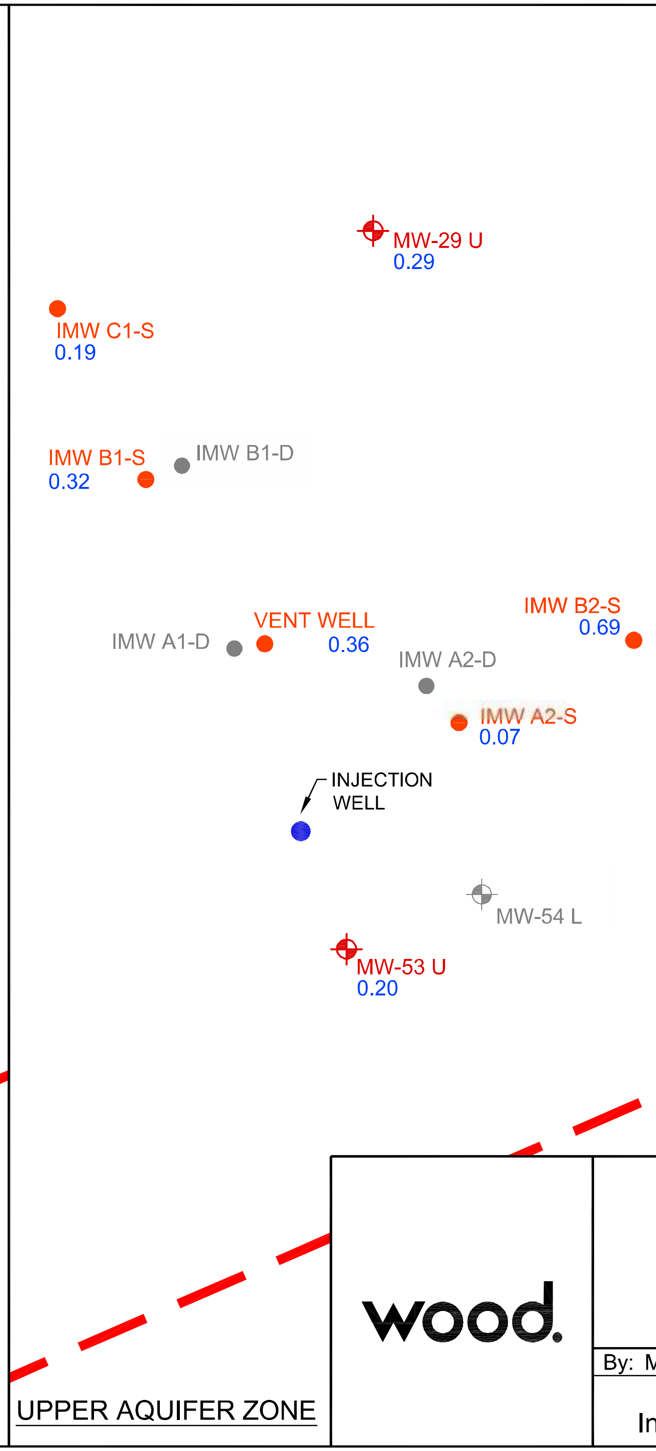
wood.

PHASE 1 INJECTION EVENT 1
GROUNDWATER MOUND CONTOURS
Former Rhone-Poulenc Site
Tukwila, Washington

| By: MDS | Date: 09/05/18 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 22 |

lot Date: 09/05/18 - 12:20pm, Plotted by: mike.stenberg
rawing Path: C:\Civil 3D Projects\Wood\FRP\FRP_Groundwater Zones 082918 - Standard\, Drawing Name: FRP_Groundwater Zones 082918.dwg




## EXPLANATION

APPROXIMATE LOCATION OF BARRIER WALL

IMW A1 — $CO_2$ INJECTION MONITORING WELL

MW-29 U — MONITORING WELL

0.29 — MAXIMUM CHANGE IN WATER LEVEL RECORDED

1' — APPROXIMATE CHANGE IN GROUNDWATER ELEVATION (DASHED WHERE INFERRED)

## MONITORING WELL NETWORK

U — UPPER ZONE MONITORING POINT

L — LOWER ZONE MONITORING POINT

-S — SHALLOW MONITORING POINT

-D — DEEP MONITORING POINT

## NOTE

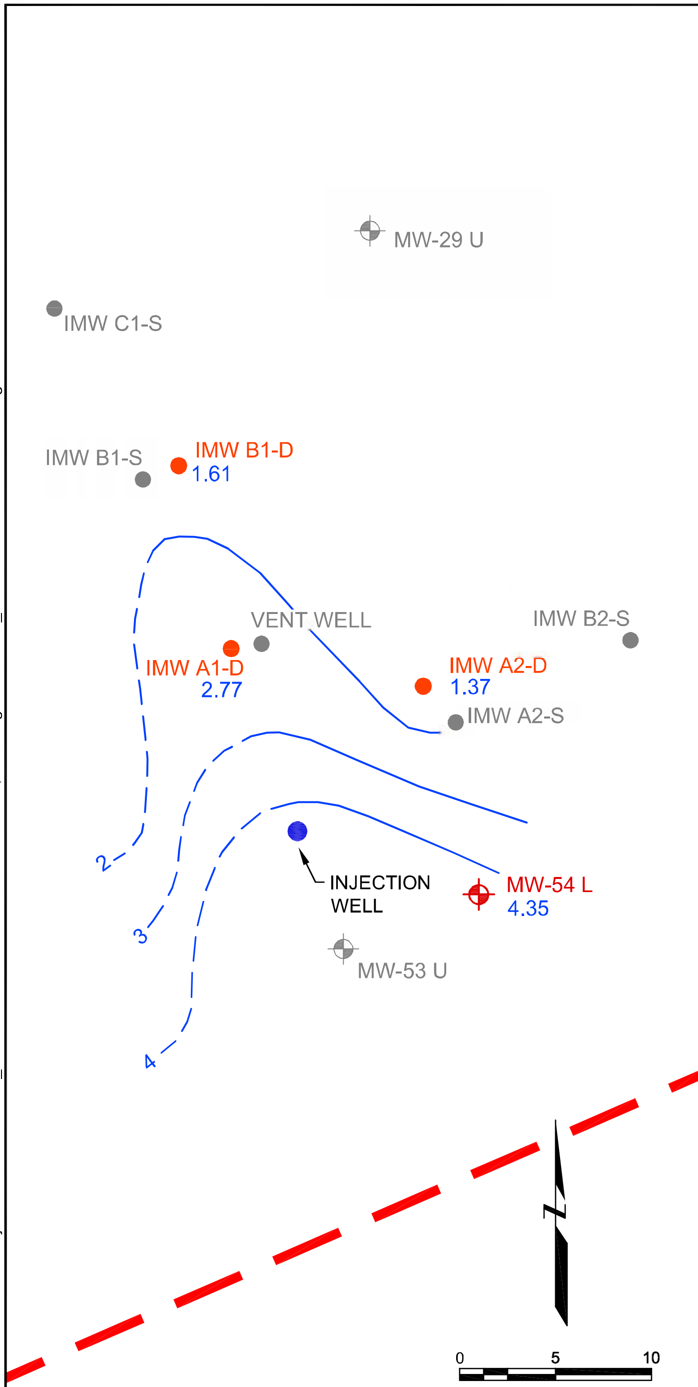
THE VALUES SHOWN ARE THE INCREASE FROM THE "30 MINUTE AVERAGE WATER LEVEL MEASURED PRIOR TO THE INJECTION EVENT."
WATER LEVEL INCREASES ARE MEASURED IN FEET.
THE VALUES SHOWN REPRESENT THE MAXIMUM WATERLEVEL RECORDED DURING THE INJECTION EVENT.
WELLS IN GREY WERE NOT USED WHEN DRAWING GROUNDWATER CONTOURS.

wood.

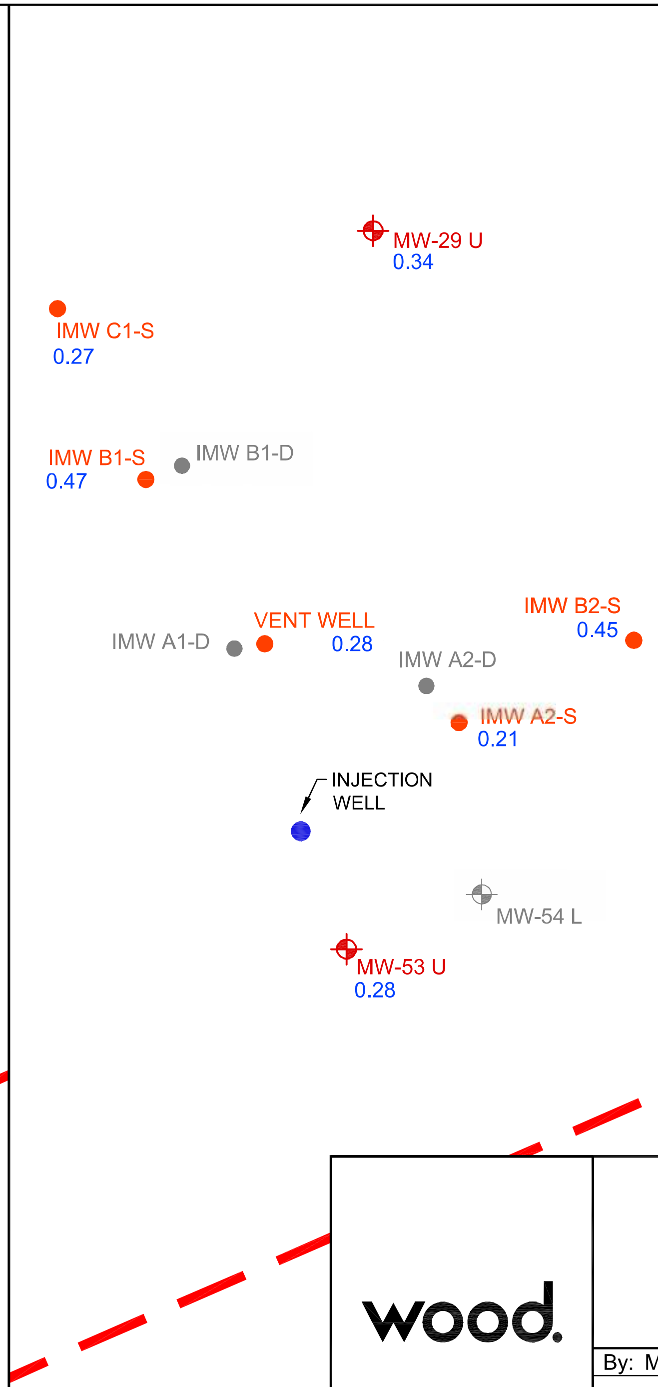
PHASE 1 INJECTION EVENT 2
GROUNDWATER MOUND CONTOURS
Former Rhone-Poulenc Site
Tukwila, Washington

| By: MDS | Date: 09/05/18 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 23 |

lot Date: 09/05/18 - 12:19pm, Plotted by: mike.stenberg
rawing Path: C:\Civil 3D Projects\Wood\FRP\FRP_Groundwater Zones 082918 - Standard\, Drawing Name: FRP_Groundwater Zones 082918.dwg




LOWER AQUIFER ZONE




UPPER AQUIFER ZONE

## EXPLANATION

- APPROXIMATE LOCATION OF BARRIER WALL
- IMW A1 — $CO_2$ INJECTION MONITORING WELL
- MW-29 U — MONITORING WELL
- 0.34 — MAXIMUM CHANGE IN WATER LEVEL RECORDED
- 1' — APPROXIMATE CHANGE IN GROUNDWATER ELEVATION (DASHED WHERE INFERRED)

## MONITORING WELL NETWORK

- U — UPPER ZONE MONITORING POINT
- L — LOWER ZONE MONITORING POINT
- -S — SHALLOW MONITORING POINT
- -D — DEEP MONITORING POINT

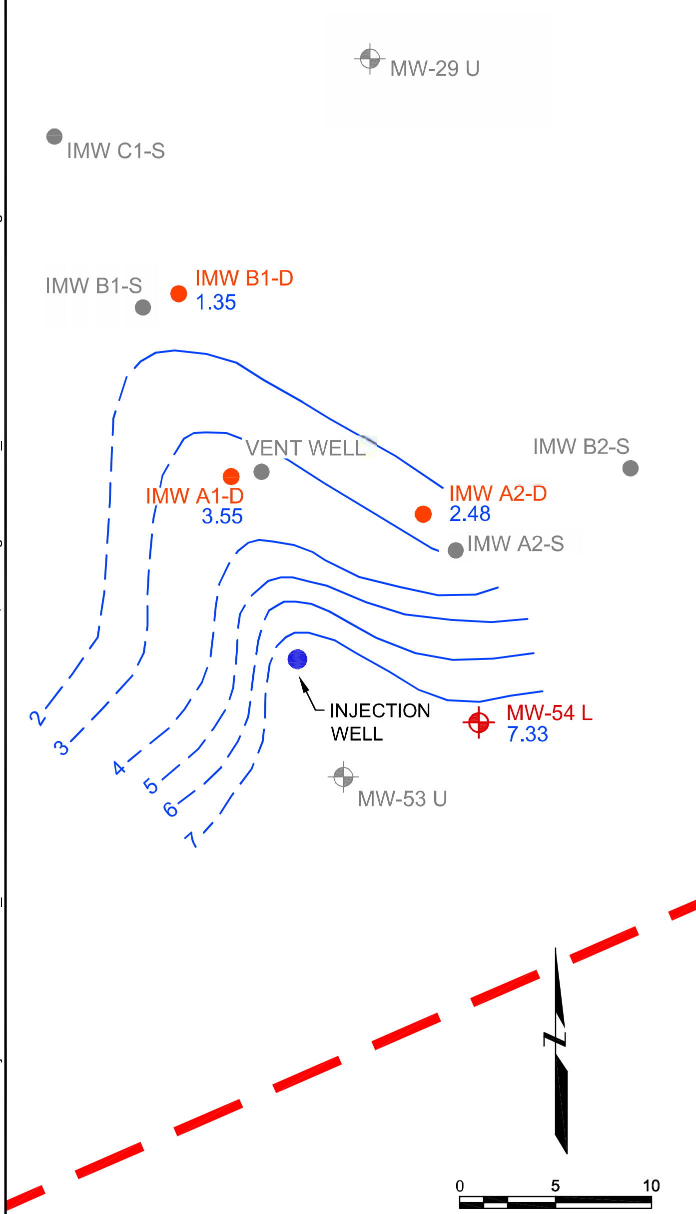
## NOTE

THE VALUES SHOWN ARE THE INCREASE FROM THE "30 MINUTE AVERAGE WATER LEVEL MEASURED PRIOR TO THE INJECTION EVENT." WATER LEVEL INCREASES ARE MEASURED IN FEET. THE VALUES SHOWN REPRESENT THE MAXIMUM WATERLEVEL RECORDED DURING THE INJECTION EVENT.
WELLS IN GREY WERE NOT USED WHEN DRAWING GROUNDWATER CONTOURS.

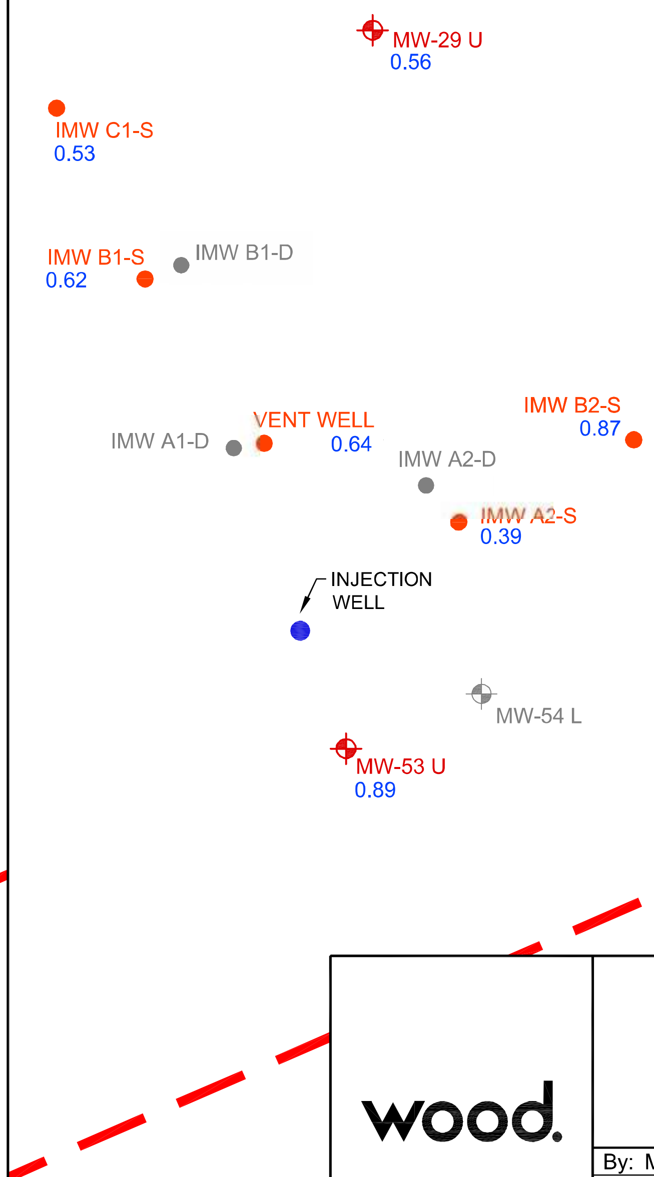
wood.

PHASE 1 INJECTION EVENT 3
GROUNDWATER MOUND CONTOURS
Former Rhone-Poulenc Site
Tukwila, Washington

| By: MDS | Date: 09/05/18 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 24 |




LOWER AQUIFER ZONE




UPPER AQUIFER ZONE

## EXPLANATION

APPROXIMATE LOCATION OF BARRIER WALL

IMW A1 — $CO_2$ INJECTION MONITORING WELL

MW-29 U — MONITORING WELL

0.56 — MAXIMUM CHANGE IN WATER LEVEL RECORDED

1' — APPROXIMATE CHANGE I GROUNDWATER ELEVATION (DASHED WHERE INFERRED)

## MONITORING WELL NETWORK

U — UPPER ZONE MONITORING POINT

L — LOWER ZONE MONITORING POINT

-S — SHALLOW MONITORING POINT

-D — DEEP MONITORING POINT

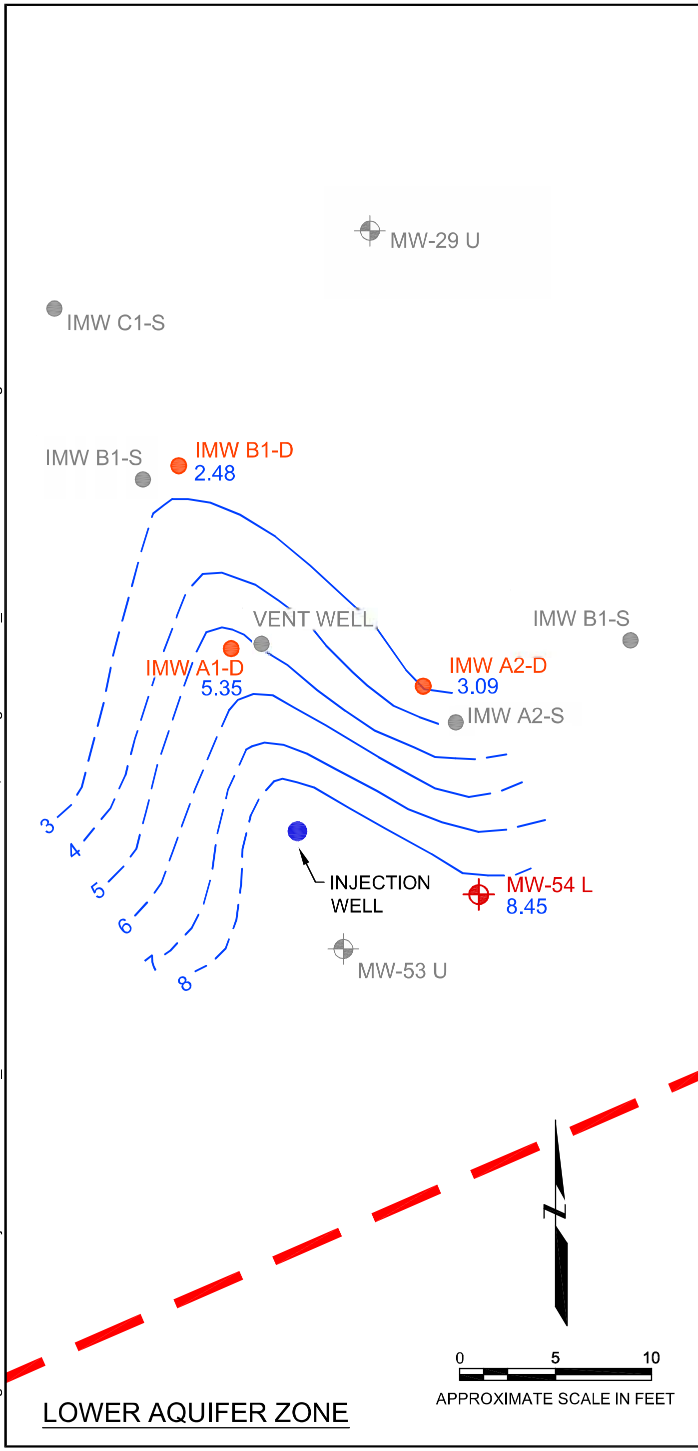
## NOTE

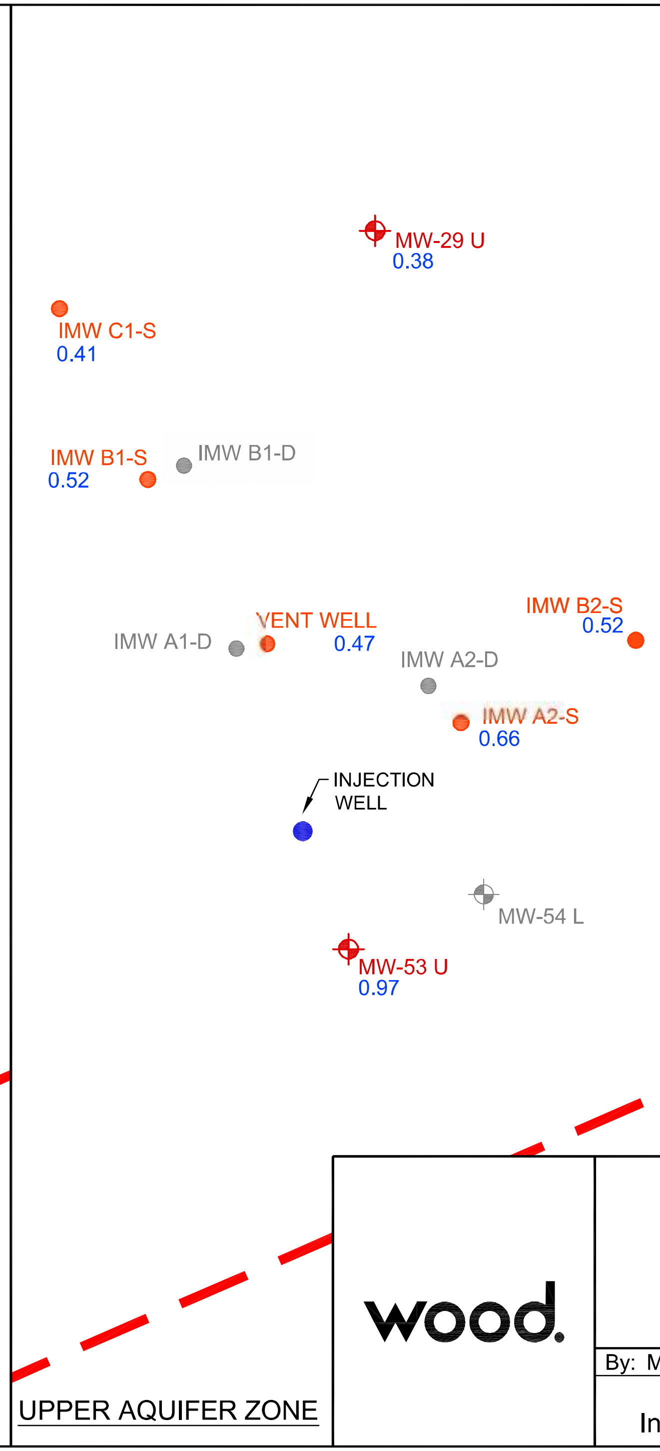
THE VALUES SHOWN ARE THE INCREASE FROM THE "30 MINUTE AVERAGE WATER LEVEL MEASURED PRIOR TO THE INJECTION EVENT."
WATER LEVEL INCREASES ARE MEASURED IN FEET.
THE VALUES SHOWN REPRESENT THE MAXIMUM WATERLEVEL RECORDED DURING THE INJECTION EVENT.
WELLS IN GREY WERE NOT USED WHEN DRAWING GROUNDWATER CONTOURS.

wood.

PHASE 1 INJECTION EVENT 4
GROUNDWATER MOUND CONTOURS
Former Rhone-Poulenc Site
Tukwila, Washington

| By: MDS | Date: 09/05/18 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 25 |




## EXPLANATION

APPROXIMATE LOCATION OF BARRIER WALL

IMW A1 — $CO_2$ INJECTION MONITORING WELL

MW-29 U — MONITORING WELL

0.38 — MAXIMUM CHANGE IN WATER LEVEL RECORDED

1' — APPROXIMATE CHANGE IN GROUNDWATER ELEVATION (DASHED WHERE INFERRED)

## MONITORING WELL NETWORK

U — UPPER ZONE MONITORING POINT

L — LOWER ZONE MONITORING POINT

-S — SHALLOW MONITORING POINT

-D — DEEP MONITORING POINT

## NOTE

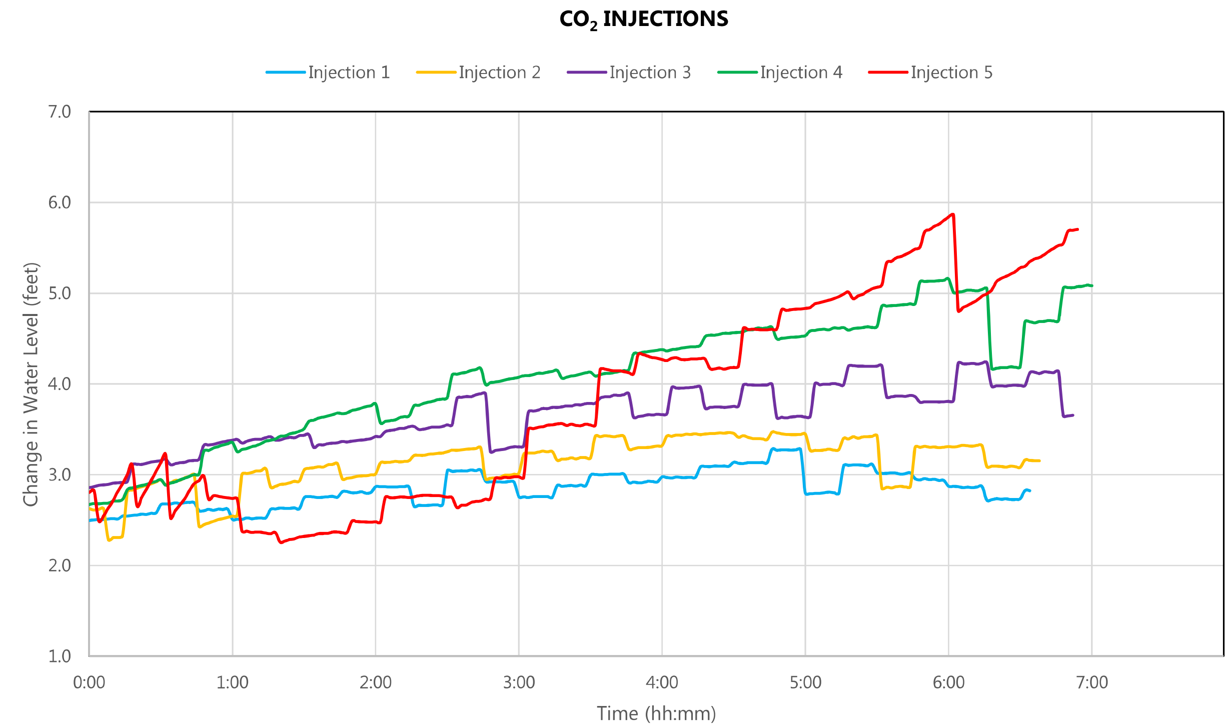
THE VALUES SHOWN ARE THE INCREASE FROM THE "30 MINUTE AVERAGE WATER LEVEL MEASURED PRIOR TO THE INJECTION EVENT."
WATER LEVEL INCREASES ARE MEASURED IN FEET.
THE VALUES SHOWN REPRESENT THE MAXIMUM WATER LEVEL RECORDED DURING THE INJECTION EVENT.
WELLS IN GREY WERE NOT USED WHEN DRAWING GROUNDWATER CONTOURS.

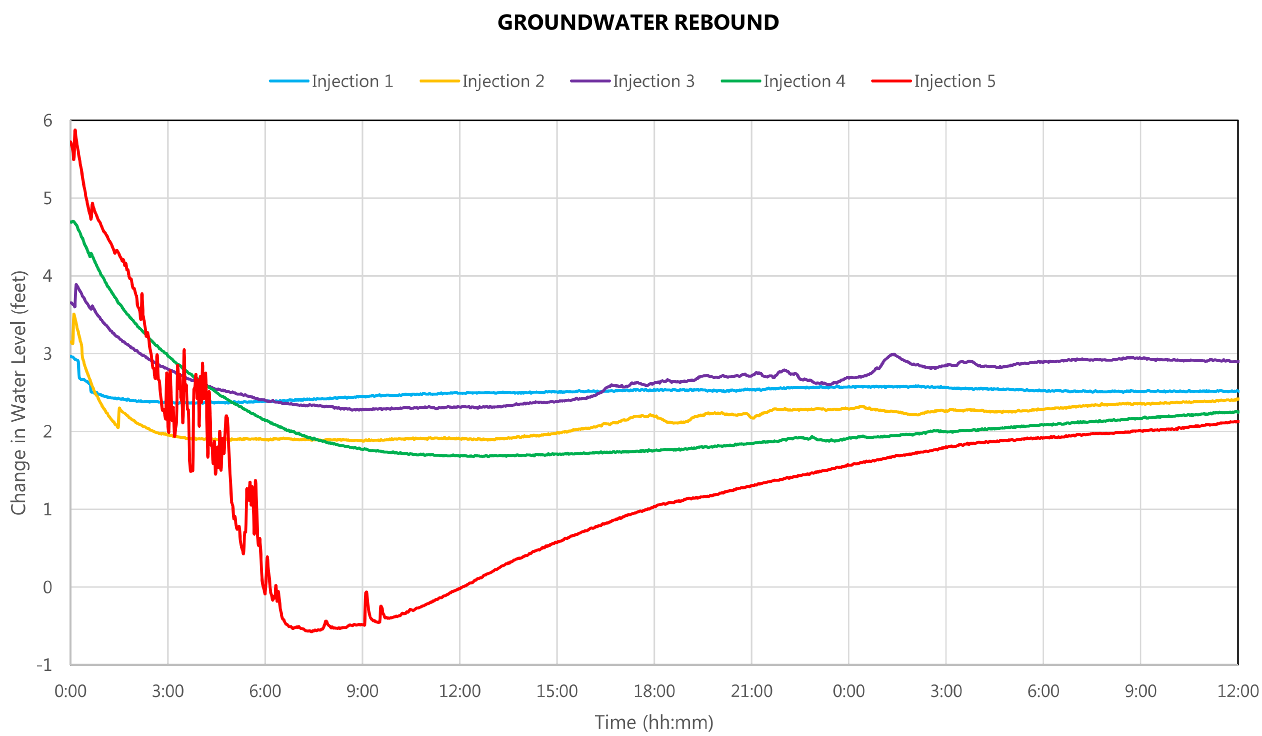
wood.

PHASE 1 INJECTION EVENT 5
GROUNDWATER MOUND CONTOURS
Former Rhone-Poulenc Site
Tukwila, Washington

| By: MDS | Date: 09/05/18 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 26 |

lot Date: 09/05/18 - 2:57pm, Plotted by: mike.stenberg
rawing Path: C:\Civil 3D Projects\Wood\FRP\FRP_Groundwater Zones 082918 - Standard\, Drawing Name: FRP_Groundwater Zones 082918.dwg




Notes

1. Water levels are based on pressure transducer readings and manual wellhead pressure readings.
2. Time is in hours from starting or ending the injection.
3. The step-like nature of the changes in water level is attributed to the collection of wellhead pressure measurements every 15 minutes. Changes in the wellhead pressure resulted in large increases and decreases of calculated water level.

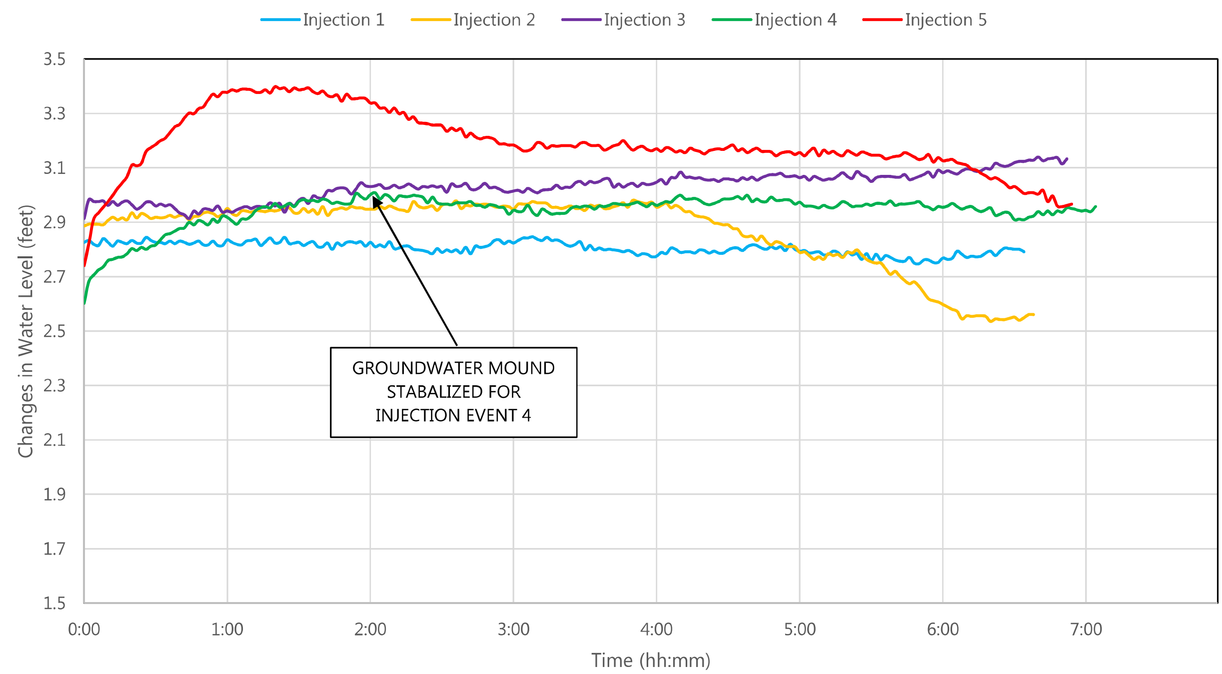
wood.

PHASE 1 IMW-A2-D WATER LEVEL CHANGE TRENDS
Former Rhone-Poulenc Site
Tukwila, WA

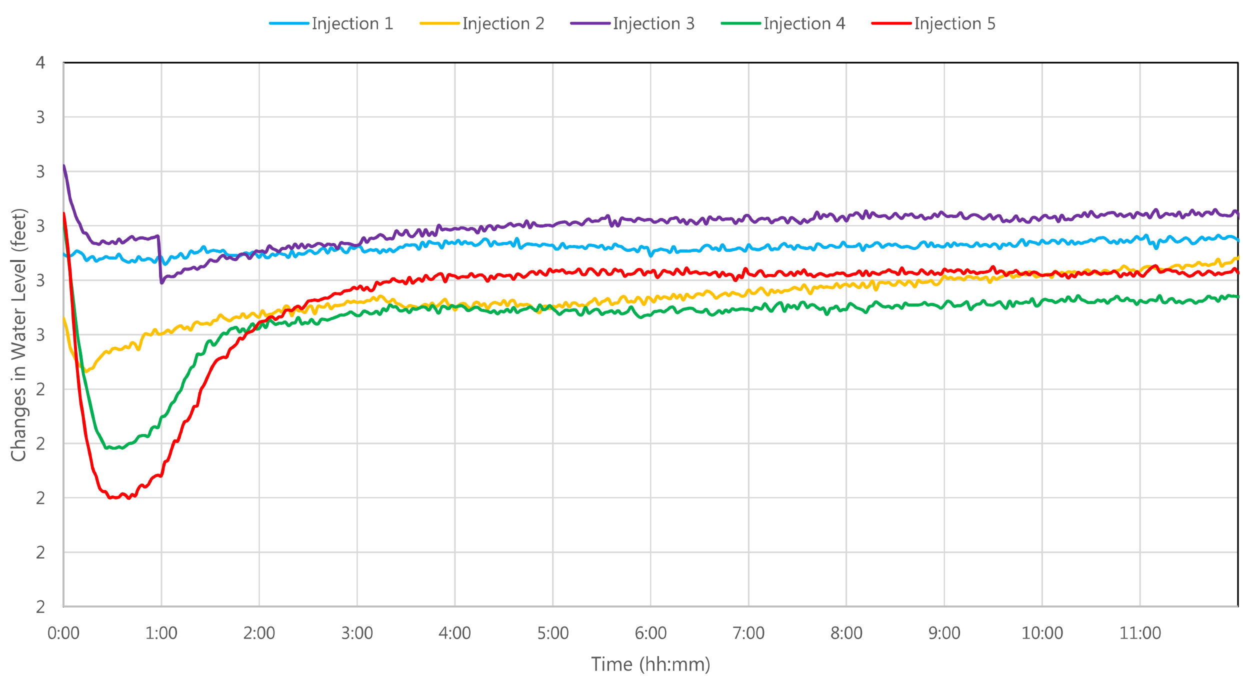
By: WMY
Project No.: 8769
Date: 9/6/2018

Figure 27

## $CO_2$ INJECTIONS




## GROUNDWATER REBOUND




Notes

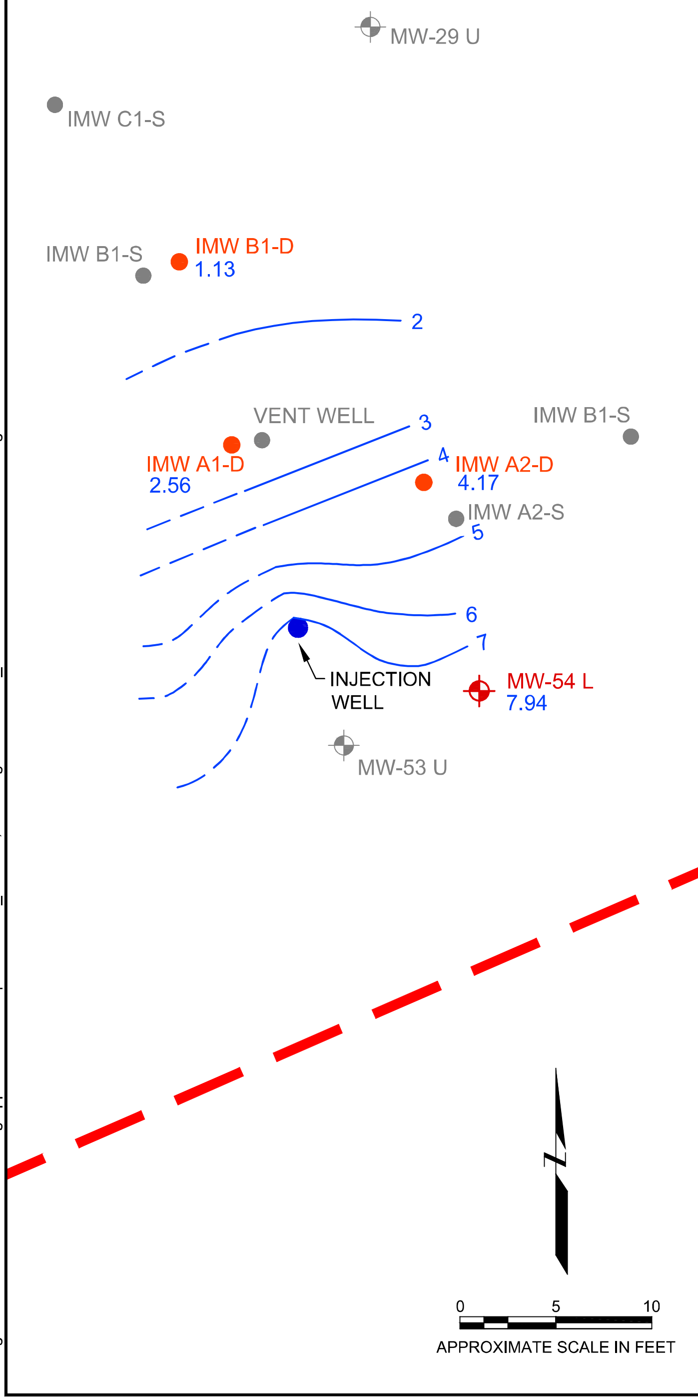
1. Water levels are based on pressure transducer readings and manual wellhead pressure readings.
2. Time is in hours from starting or ending the injection.

wood.

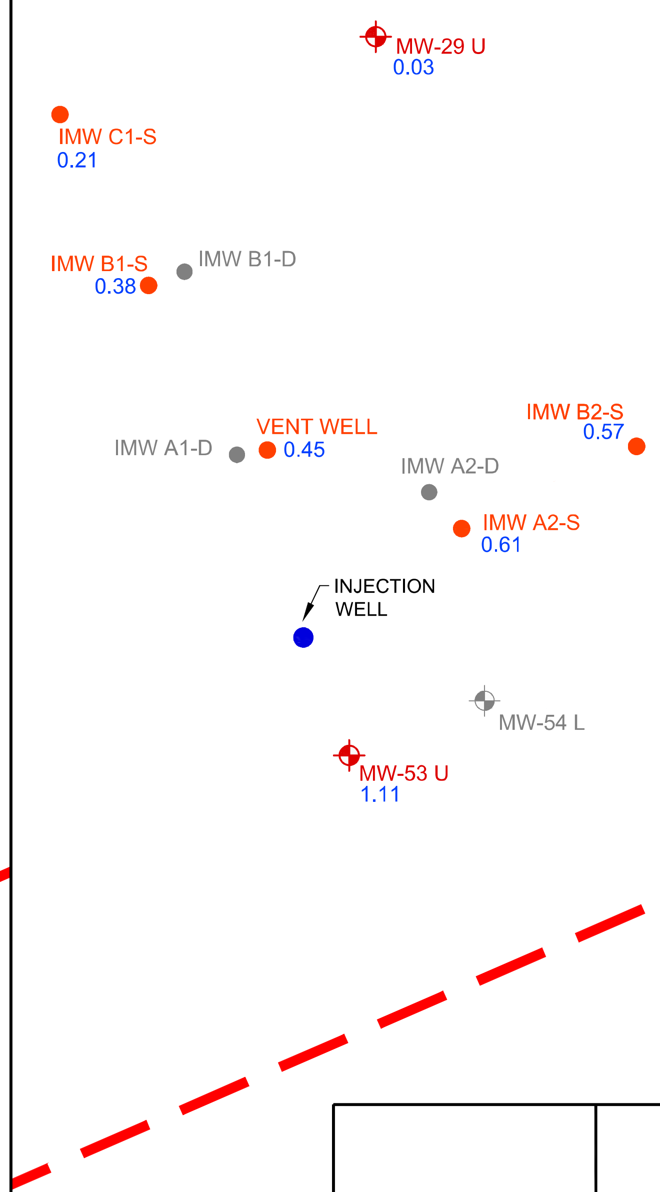
PHASE 1 IMW-A2-S WATER
LEVEL CHANGE TRENDS
Former Rhone-Poulenc Site
Tukwila, WA

| | |
|---|---|
| By: WMY | Figure 28 |
| Project No.: 8769 | |
| Date: 9/6/2018 | |

## LOWER AQUIFER ZONE




## UPPER AQUIFER ZONE




## EXPLANATION

APPROXIMATE LOCATION OF BARRIER WALL

IMW A1 — $CO_2$ INJECTION MONITORING WELL

MW-29 U — MONITORING WELL

0.03 — MAXIMUM CHANGE IN WATER LEVEL RECORDED

1' — APPROXIMATE CHANGE IN GROUNDWATER ELEVATION (DASHED WHERE INFERRED)

## MONITORING WELL NETWORK

U — UPPER ZONE MONITORING POINT

L — LOWER ZONE MONITORING POINT

-S — SHALLOW MONITORING POINT

-D — DEEP MONITORING POINT

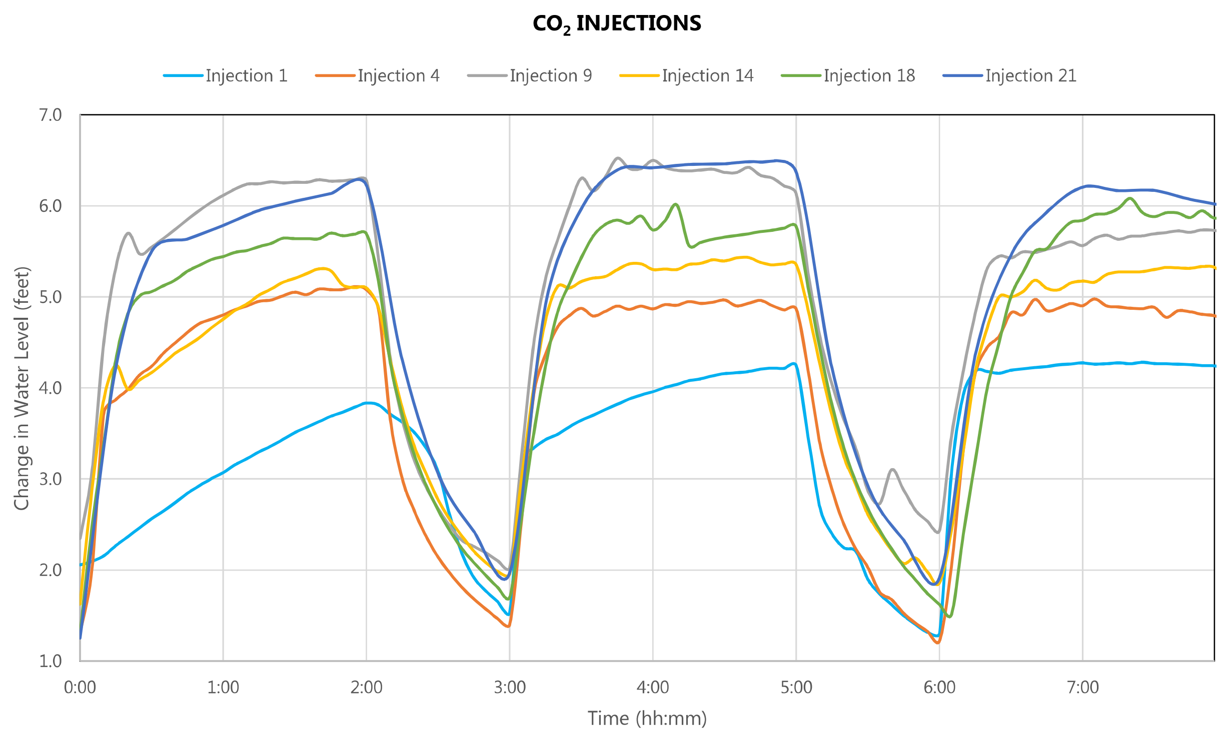
## NOTE

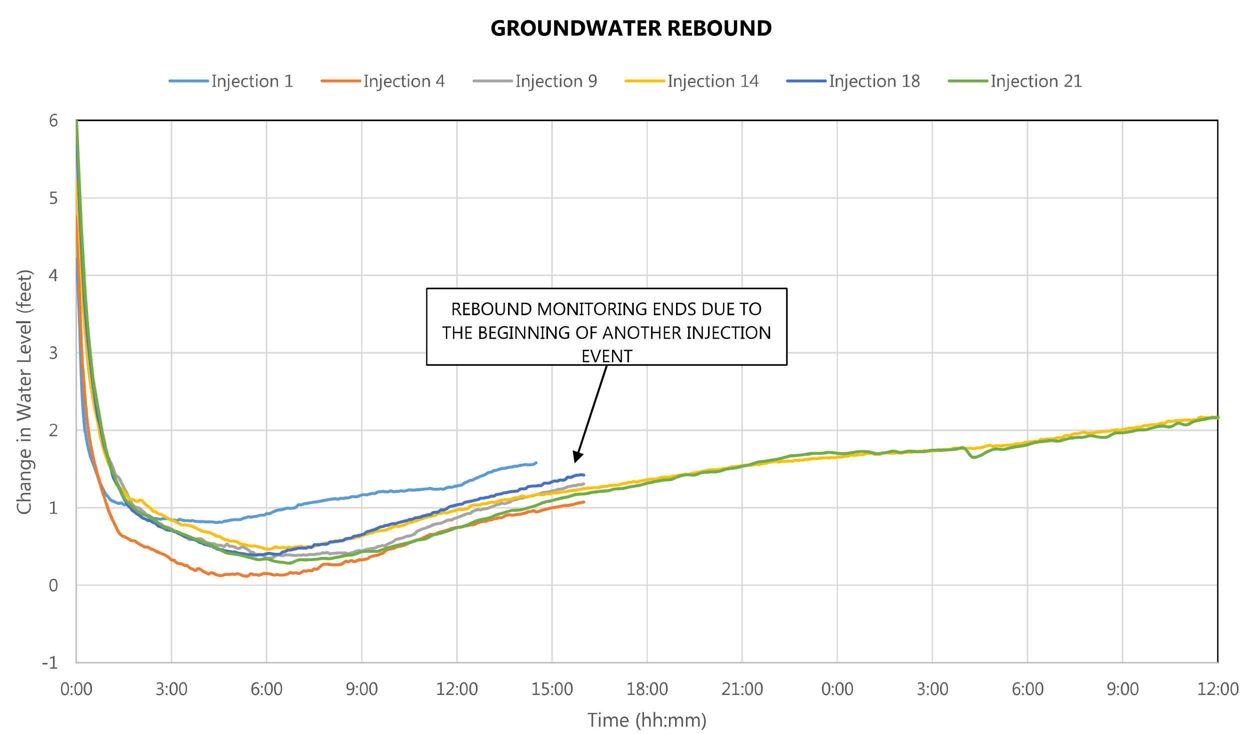
THE VALUES SHOWN ARE THE INCREASE FROM THE "30 MINUTE AVERAGE WATER LEVEL MEASURED PRIOR TO THE INJECTION EVENT."
WATER LEVEL INCREASES ARE MEASURED IN FEET.
THE VALUES SHOWN REPRESENT THE MAXIMUM WATERLEVEL RECORDED DURING THE INJECTION EVENT.
WELLS IN GREY WERE NOT USED WHEN DRAWING GROUNDWATER CONTOURS.

wood.

PHASE 3 INJECTION EVENT 9
GROUNDWATER MOUND CONTOURS
Former Rhone-Poulenc Site
Tukwila, Washington

| By: MDS | Date: 05/01/20 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 29 |



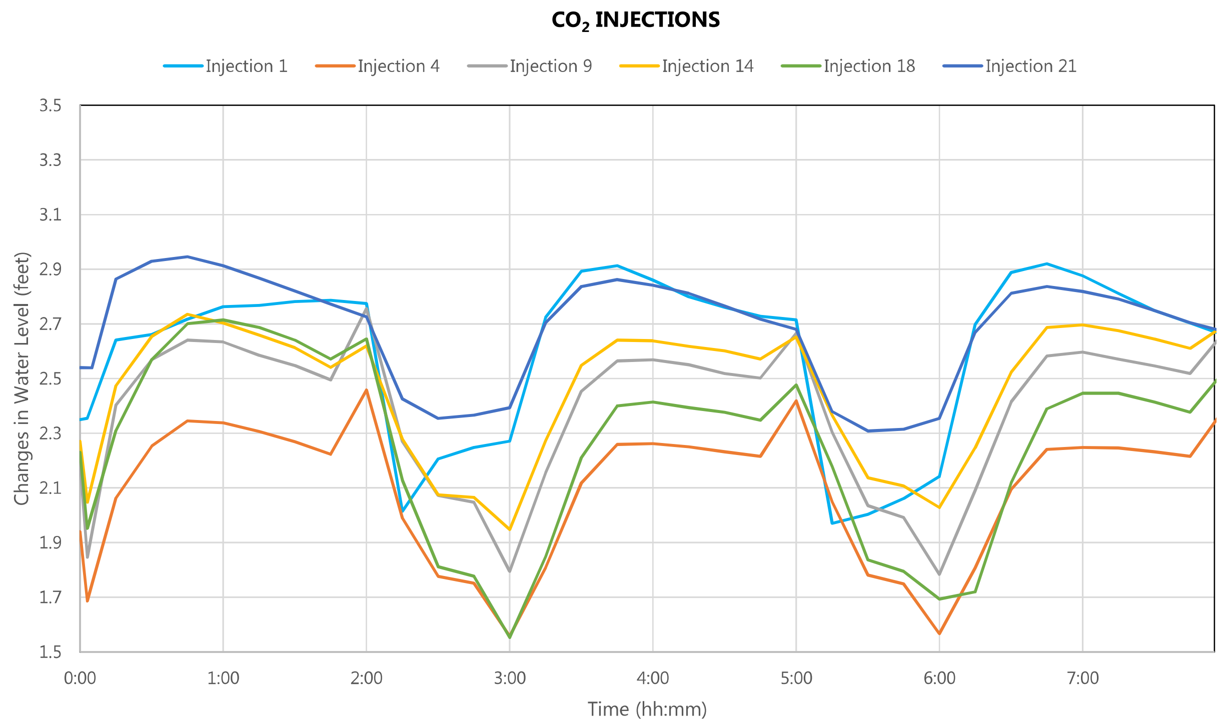



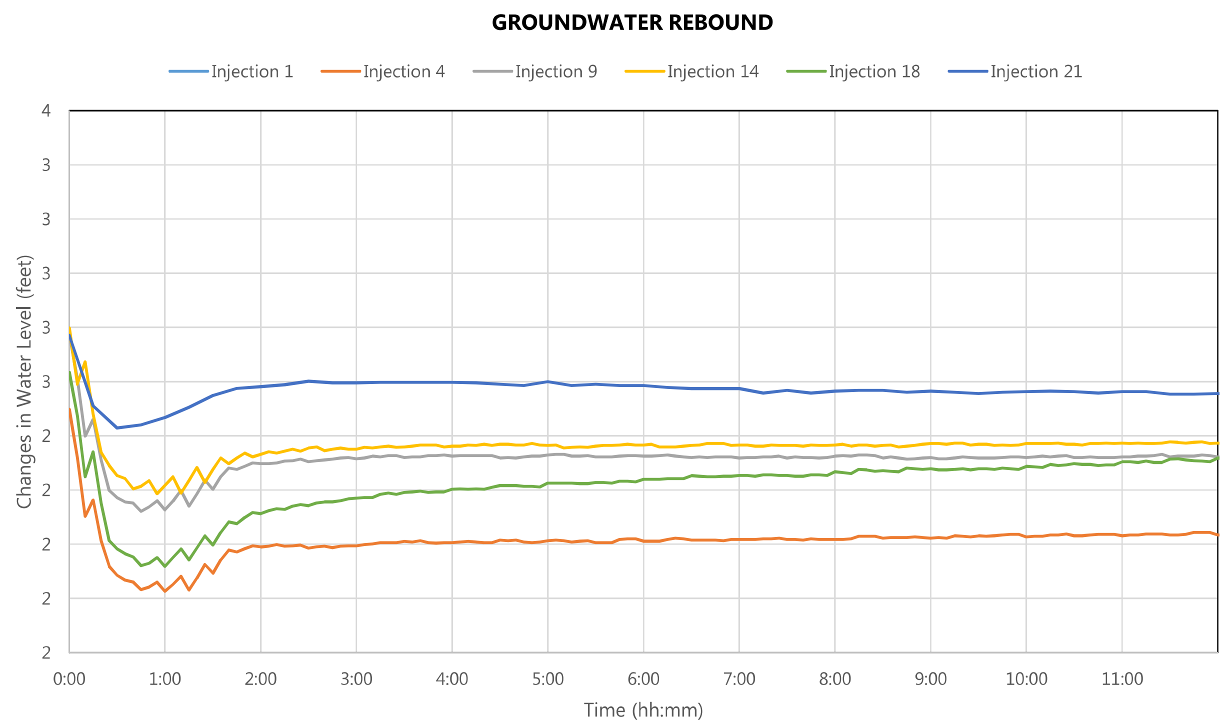

Notes

1. Water levels are based on pressure transducer readings and manual wellhead pressure readings.

2. Time is in hours from starting or ending the injection.

| | | |
|---|---|---|
| wood. | PHASE 3 IMW-A2-D WATER LEVEL CHANGE TRENDS<br>Former Rhone-Poulenc Site<br>Tukwila, WA | |
| | By: WMY<br>Project No.: 8769<br>Date: 5/14/2020 | Figure 30 |

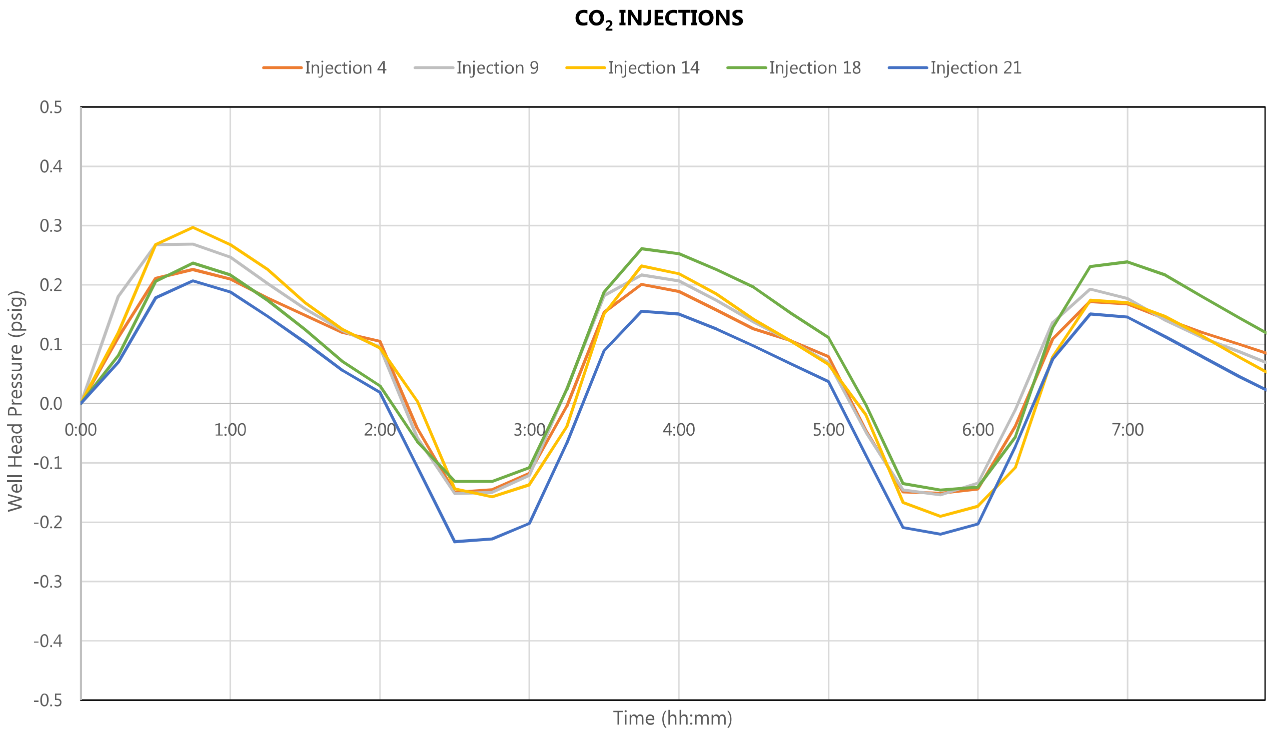


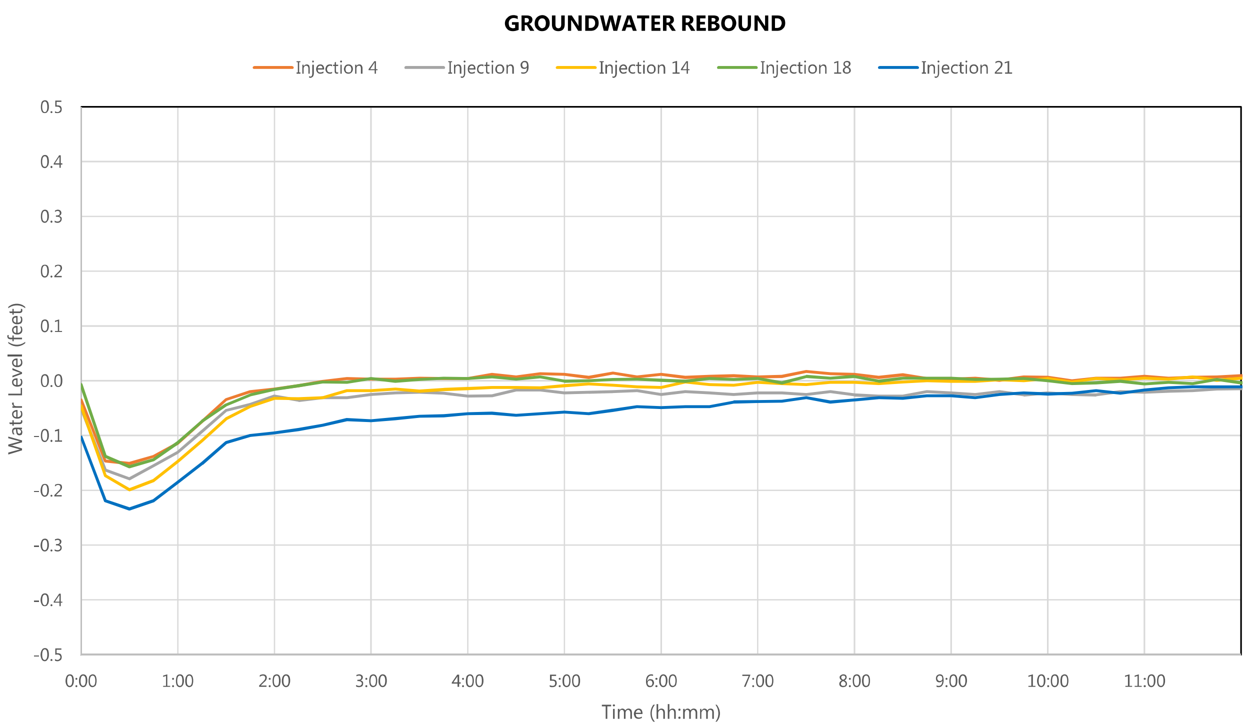




Notes

1. Water levels are based on pressure transducer readings.
2. Time is in hours from starting or ending the injection.
3. The step-like nature of the changes in water level is attributed to the collection of wellhead pressure measurements every 15 minutes. Changes in the wellhead pressure resulted in large increases and decreases of calculated water level.

| | |
|---|---|
| wood. | PHASE 3 IMW-A2-S WATER LEVEL CHANGE TRENDS<br>Former Rhone-Poulenc Site<br>Tukwila, WA |
| By: WMY<br>Project No.: 8769<br>Date: 5/14/2020 | Figure 31 |




Notes

1. Wellhead pressure is based on pressure transducer readings.
2. Time is in hours from starting or ending the injection.
3. Headspace measurements were collected every 15 minutes.

Abbreviations

psig = pounds per square inch (gauge)

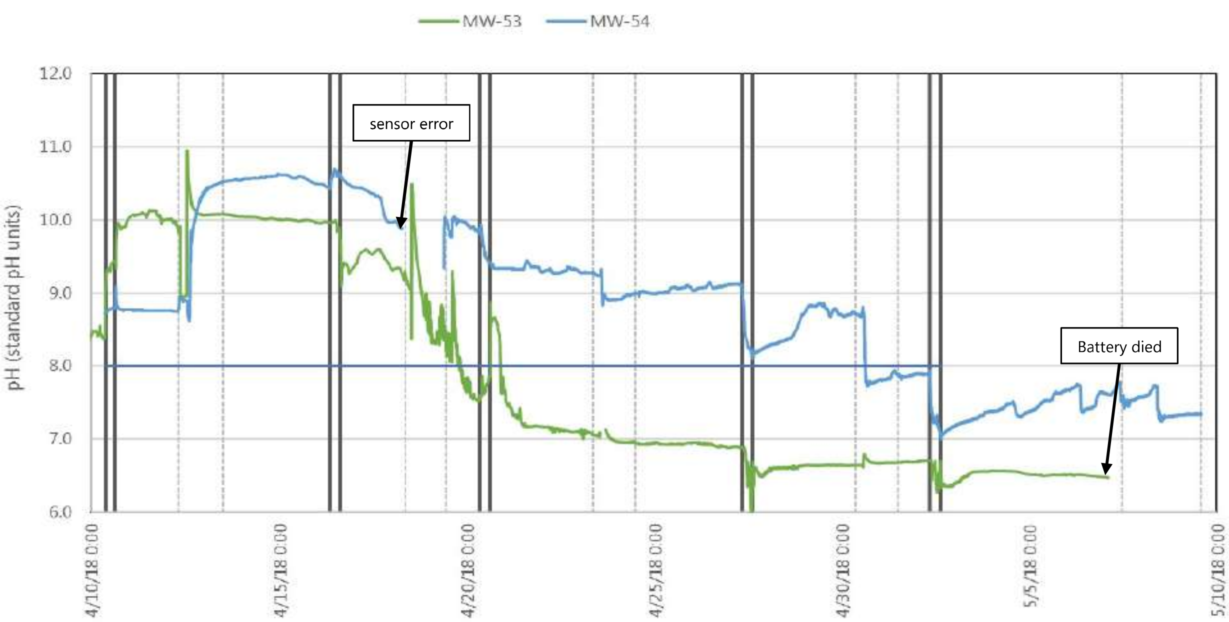
wood.

PHASE 3 IMW-A2-S HEAD SPACE TRENDS
Former Rhone-Poulenc Site
Tukwila, WA

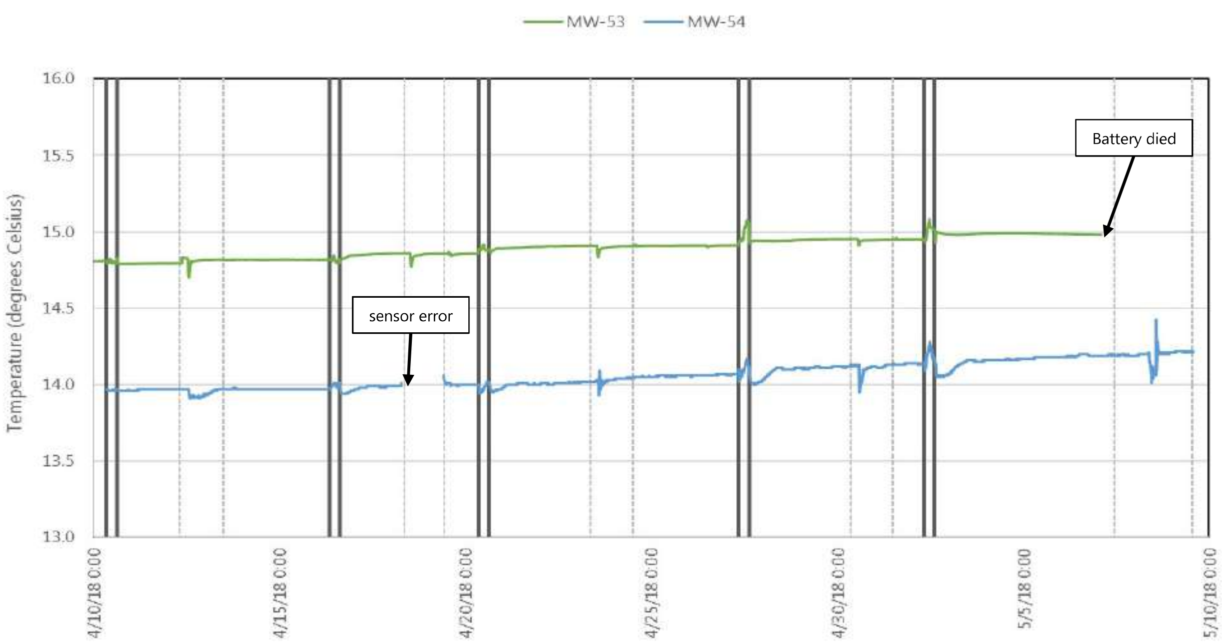
By: WMY
Project No.: 8769
Date: 5/14/2020

Figure 32

## Groundwater pH




## Groundwater Temperature



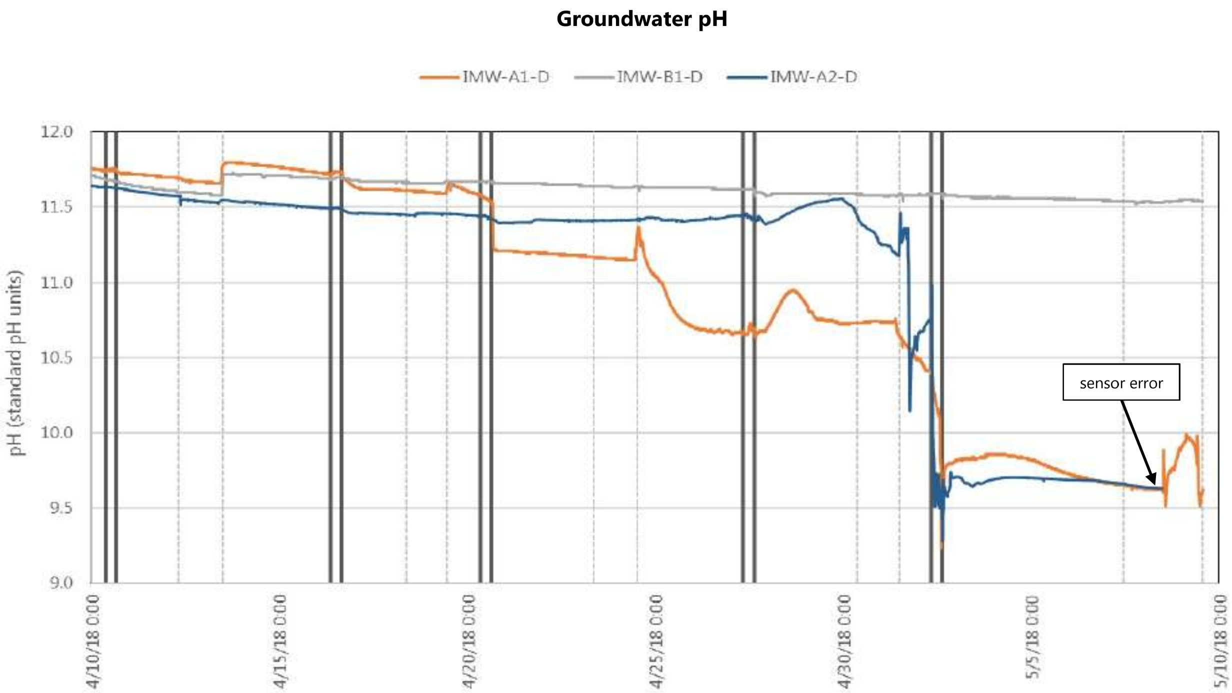

Notes

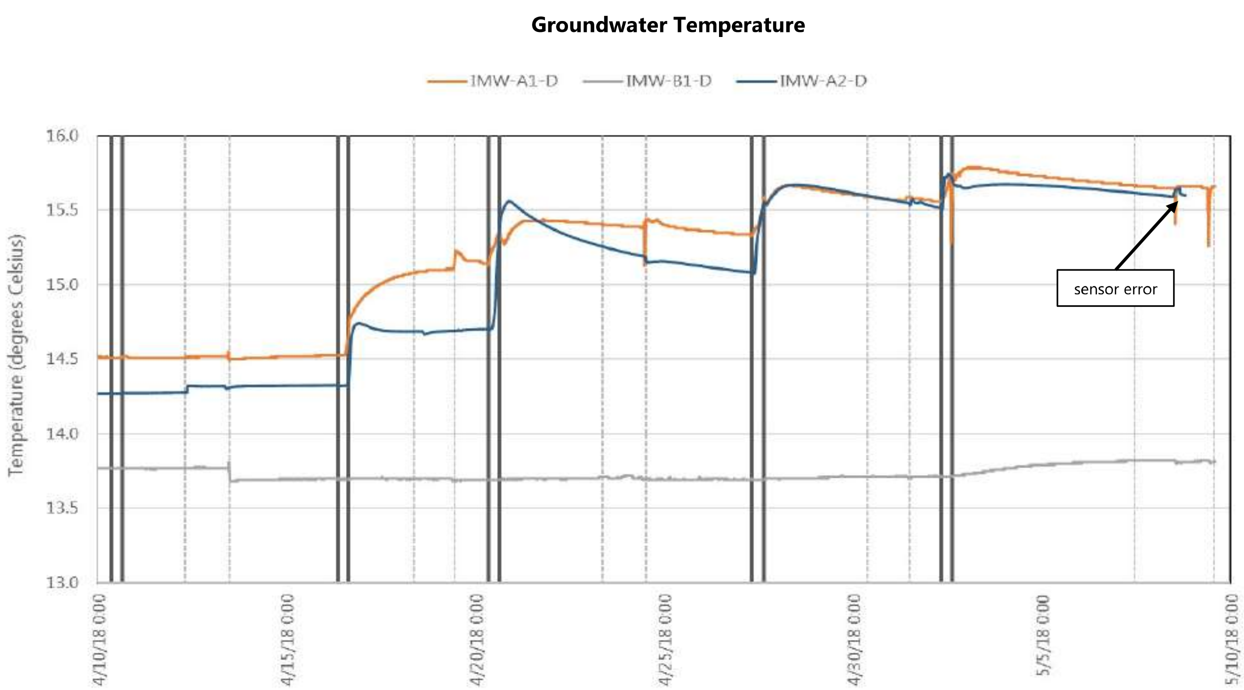
1. Solid black vertical lines represent the start and finish times of $CO_2$ injection events.

2. Dashed grey vertical lines represent the start and finish times of the collection of groundwater samples. The first line after an injection represents the time purging began on the first well sampled. The next line represents the sample collection time of the last well sampled.

3. pH sensors were calibrated prior to first injection event.

| | | |
|---|---|---|
| wood. | PHASE 1 MW-53/54 pH AND TEMPERATURE TREND PLOT<br>Former Rhone-Poulenc Site<br>Tukwila, WA | |
| | By: WMY | Figure 33 |
| | Project No.: 8769 | |
| | Date: 4/30/2020 | |




Notes

1. Solid black vertical lines represent the start and finish times of $CO_2$ injection events.

2. Dashed grey vertical lines represent the start and finish times of the collection of groundwater samples. The first line after an injection represents the time purging began on the first well sampled. The next line represents the sample collection time of the last well sampled.

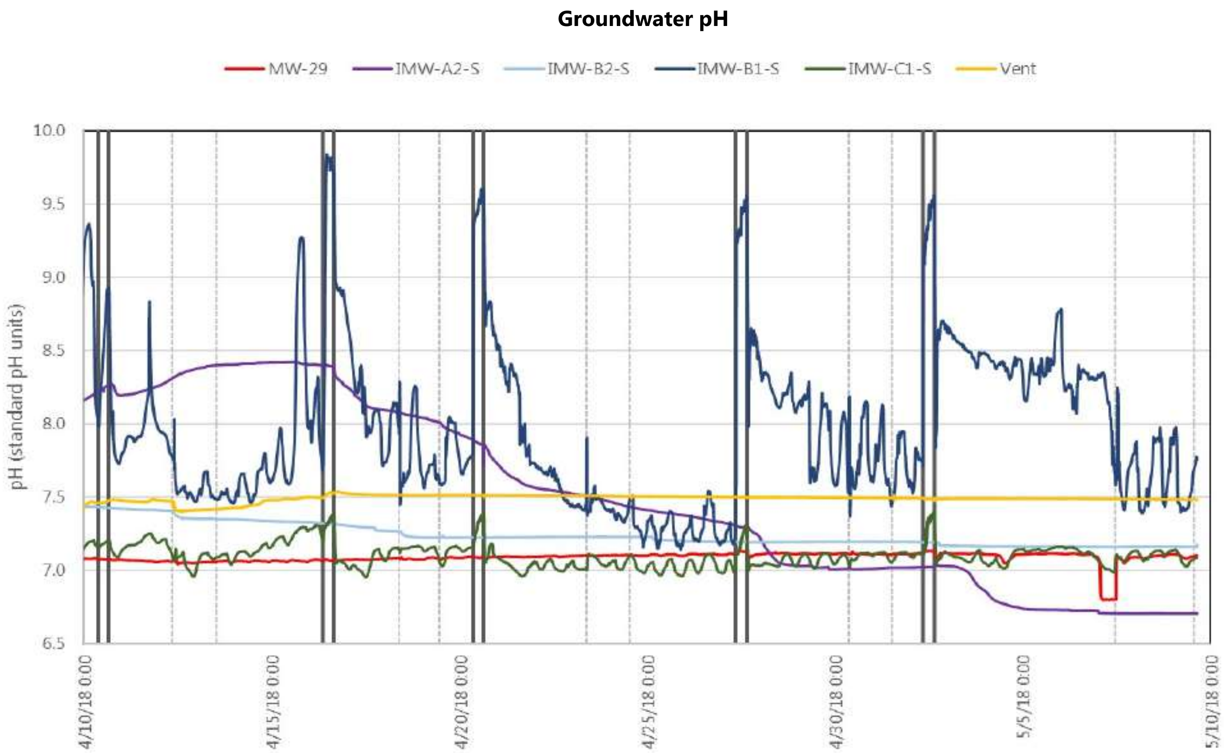
3. pH sensors were calibrated prior to first injection event.

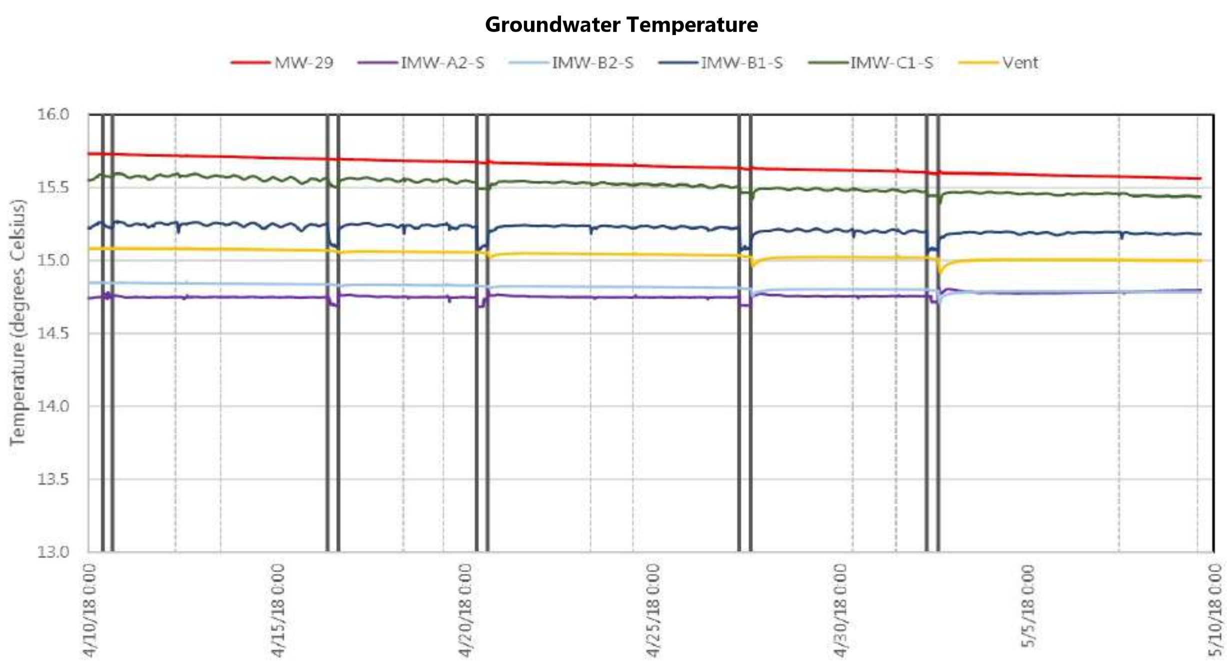
4. The observed jumps during the groundwater sampling intervals appear to be a result of purging each well.

wood.

PHASE 1 DEEP WELLS pH AND TEMPERATURE TREND PLOT
Former Rhone-Poulenc Site
Tukwila, WA

| | |
|---|---|
| By: WMY | Figure 34 |
| Project No.: 8769 | |
| Date: 4/30/2020 | |




Notes

1. Solid black vertical lines represent the start and finish times of $CO_2$ injection events.

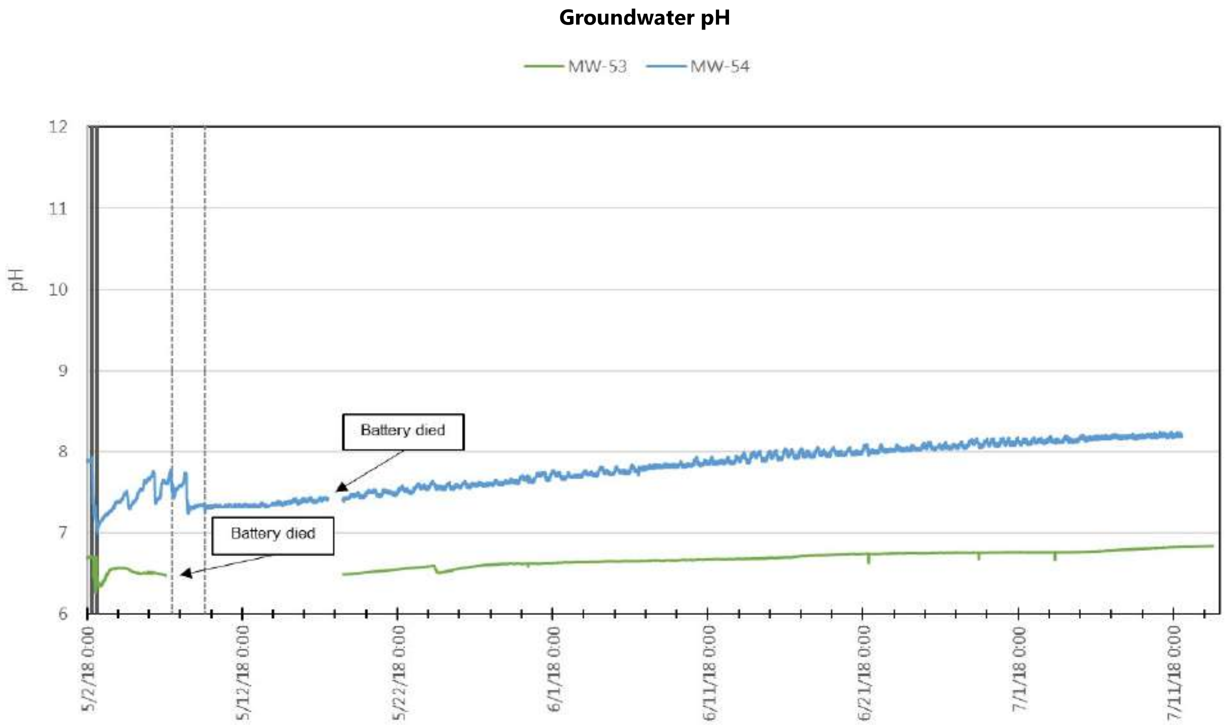
2. Dashed grey vertical lines represent the start and finish times of the collection of groundwater samples. The first line after an injection represents the time purging began on the first well sampled. The next line represents the sample collection time of the last well sampled.

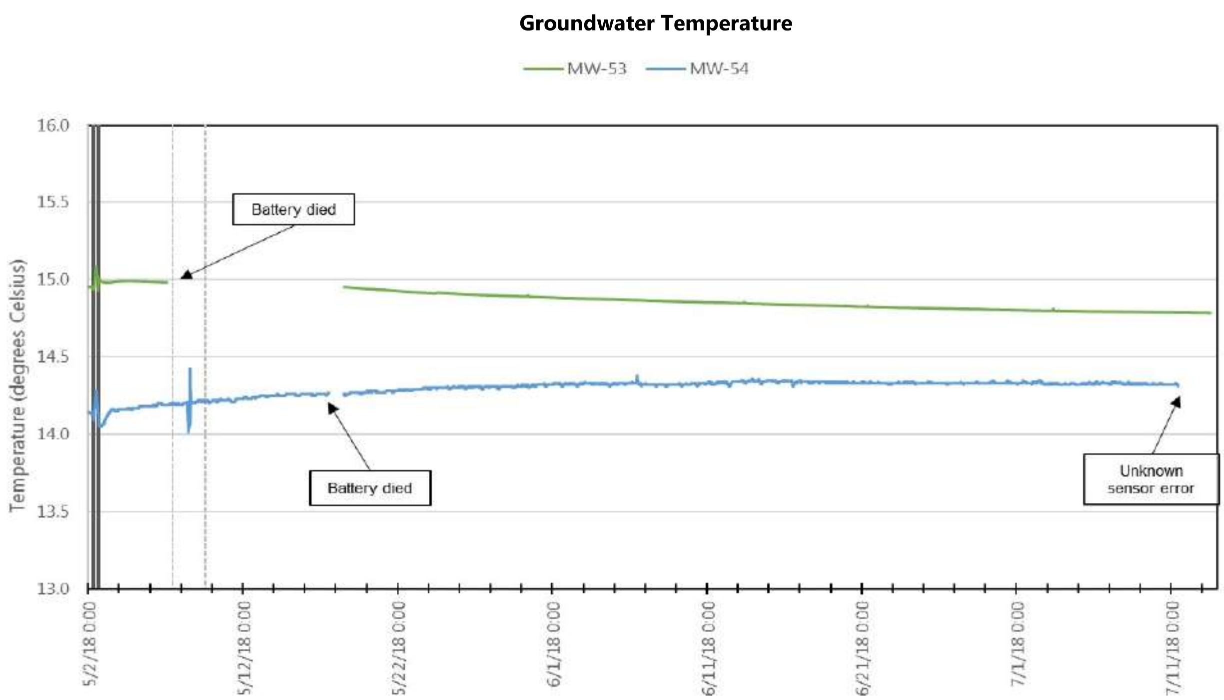
3. pH sensors were calibrated prior to first injection event.

wood.

PHASE 1 SHALLOW WELLS pH AND TEMPERATURE TREND PLOT
Former Rhone-Poulenc Site
Tukwila, WA

| | |
|---|---|
| By: WMY | Figure 35 |
| Project No.: 8769 | |
| Date: 4/30/2020 | |



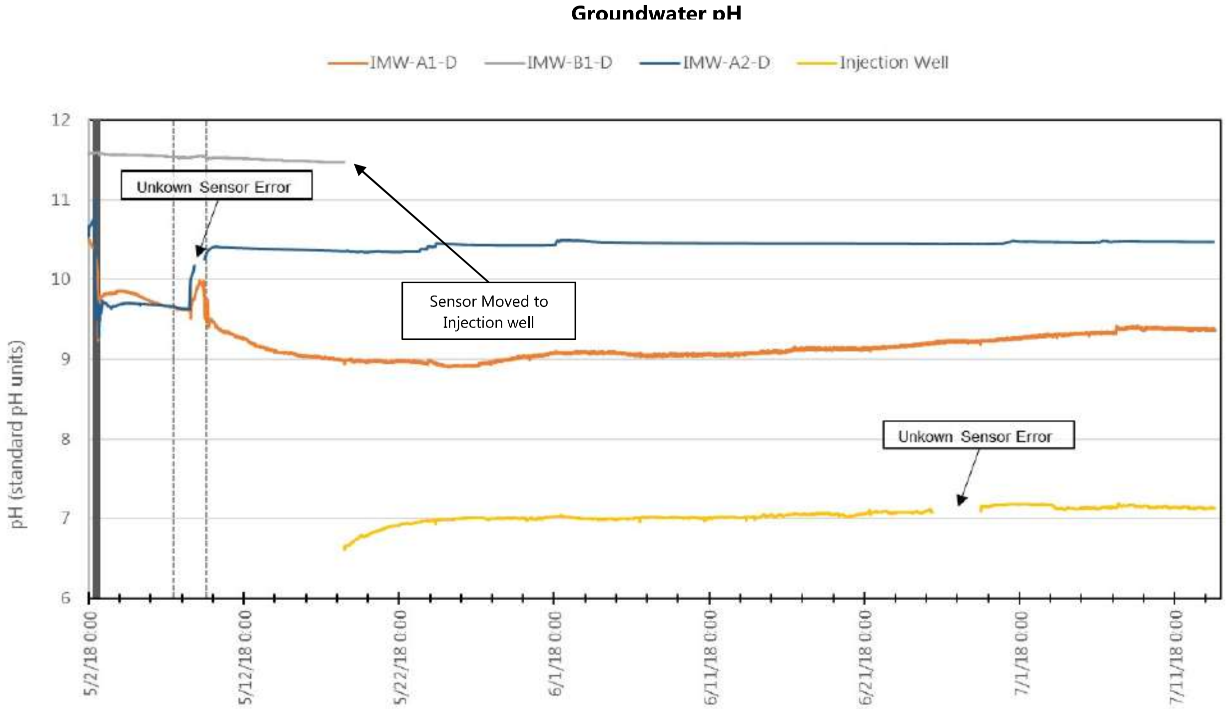

Notes

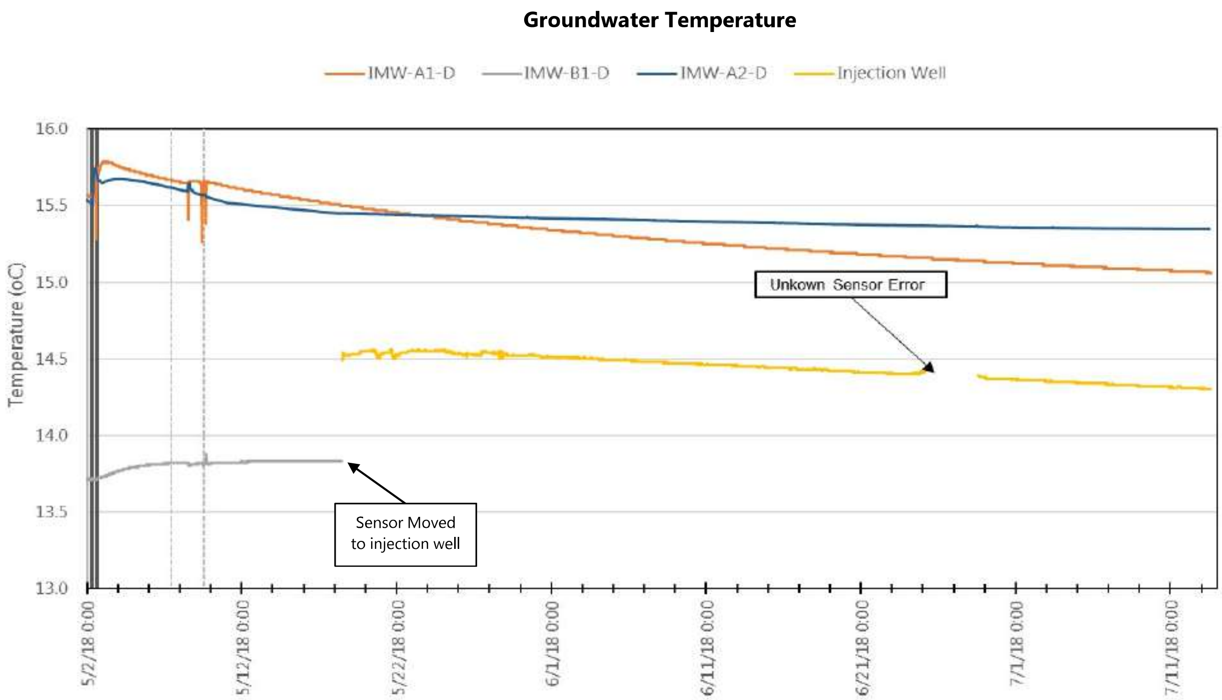
1. Solid black vertical lines represent the start and finish times of $CO_2$ injection events.

2. Dashed grey vertical lines represent the start and finish times of the collection of groundwater samples. The first line after an injection represents the time purging began on the first well sampled. The next line represents the sample collection time of the last well sampled.

3. pH sensors were calibrated prior to first injection event.

| | | |
|---|---|---|
| wood. | PHASE 2 MW-53/54 pH AND TEMPERATURE TREND PLOT<br>Former Rhone-Poulenc Site<br>Tukwila, WA | |
| | By: WMY | Figure 36 |
| | Project No.: 8769 | |
| | Date: 4/30/2020 | |




Notes

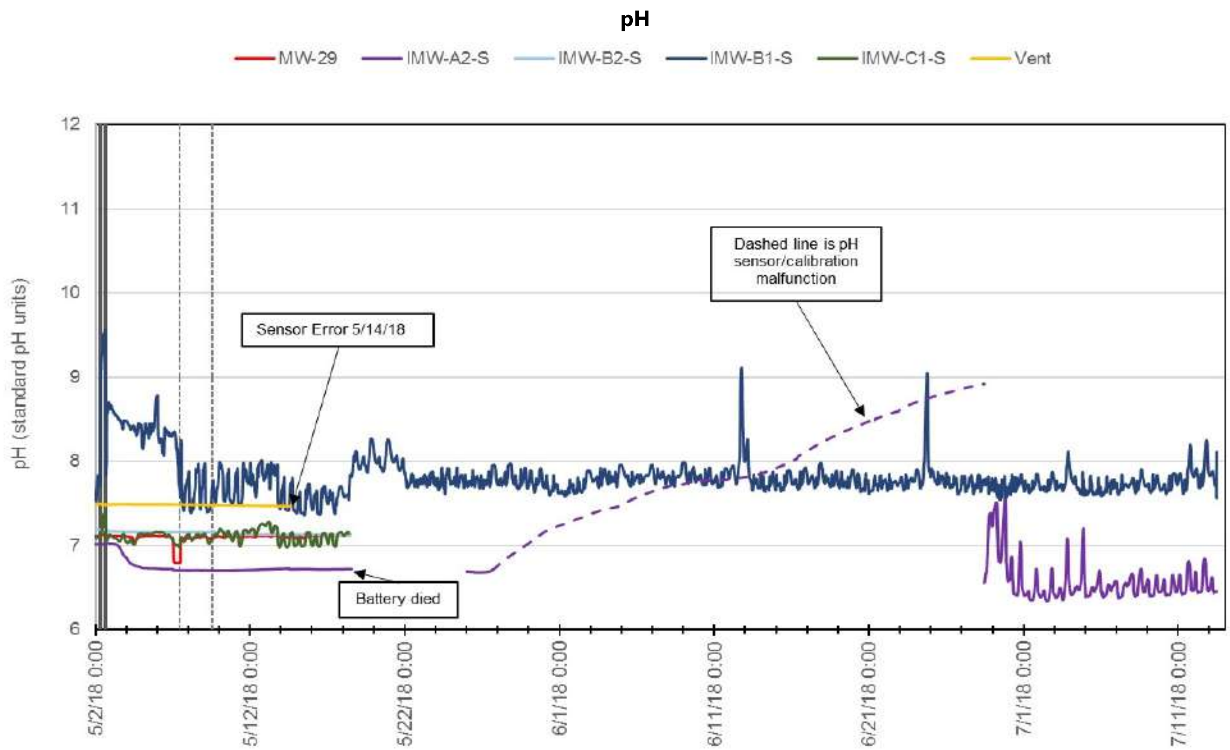
1. Solid black vertical lines represent the start and finish times of $CO_2$ injection events.

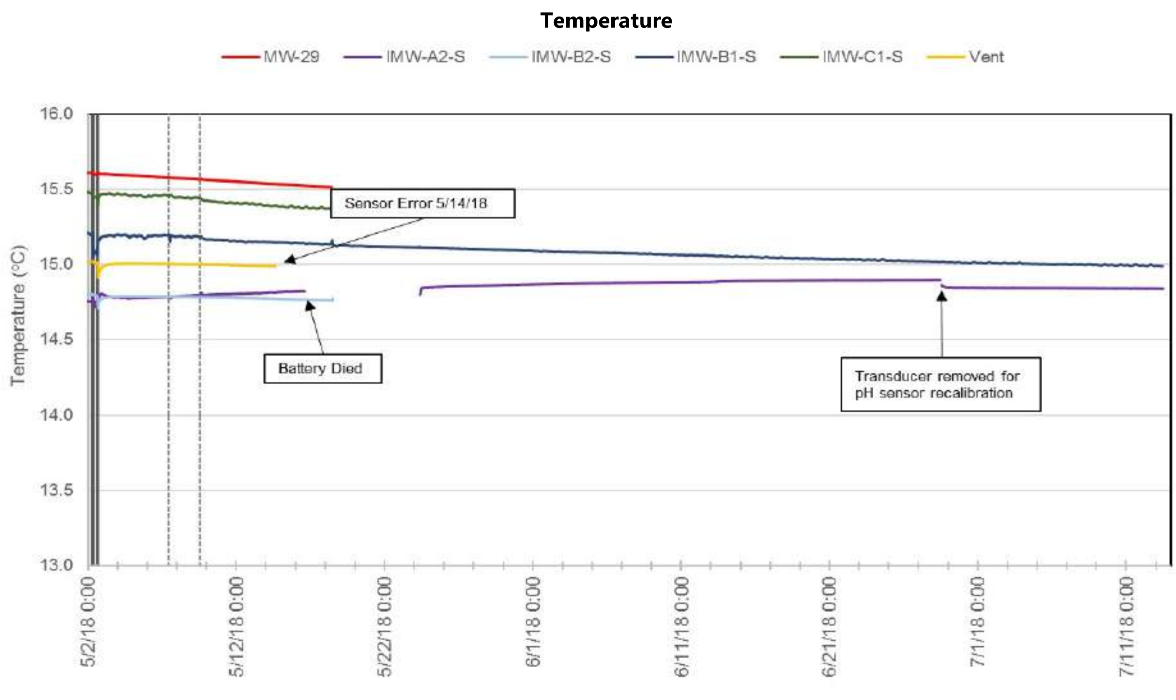
2. Dashed grey vertical lines represent the start and finish times of the collection of groundwater samples. The first line after an injection represents the time purging began on the first well sampled. The next line represents the sample collection time of the last well sampled.

3. pH sensors were calibrated prior to first injection event.

4. The observed jumps during the groundwater sampling intervals appear to be a result of

| | |
|---|---|
| wood. | PHASE 2 DEEP WELLS pH AND TEMPERATURE TREND PLOT<br>Former Rhone-Poulenc Site<br>Tukwila, WA |
| By: WMY<br>Project No.: 8769<br>Date: 4/30/2020 | Figure 37 |




Notes

1. Solid black vertical lines represent the start and finish times of $CO_2$ injection events.

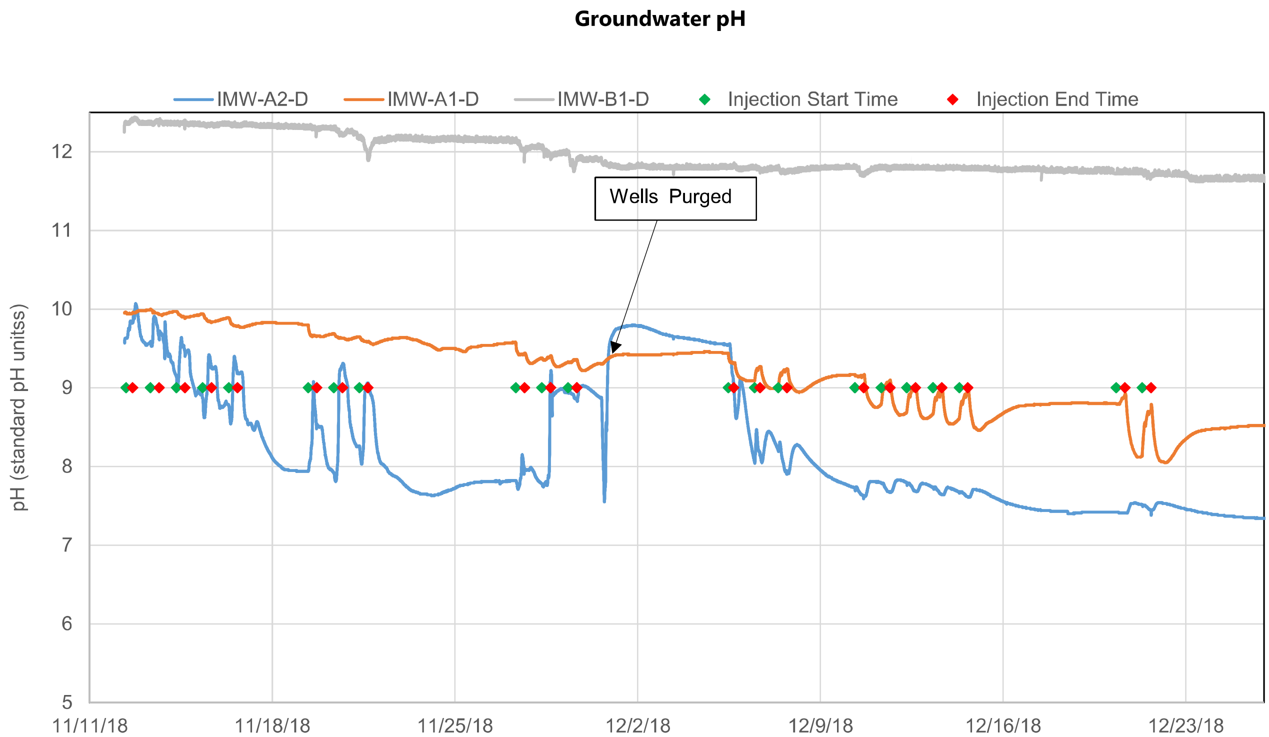
2. Dashed grey vertical lines represent the start and finish times of the collection of groundwater samples. The first line after an injection represents the time purging began on the first well sampled. The next line represents the sample collection time of the last well sampled.

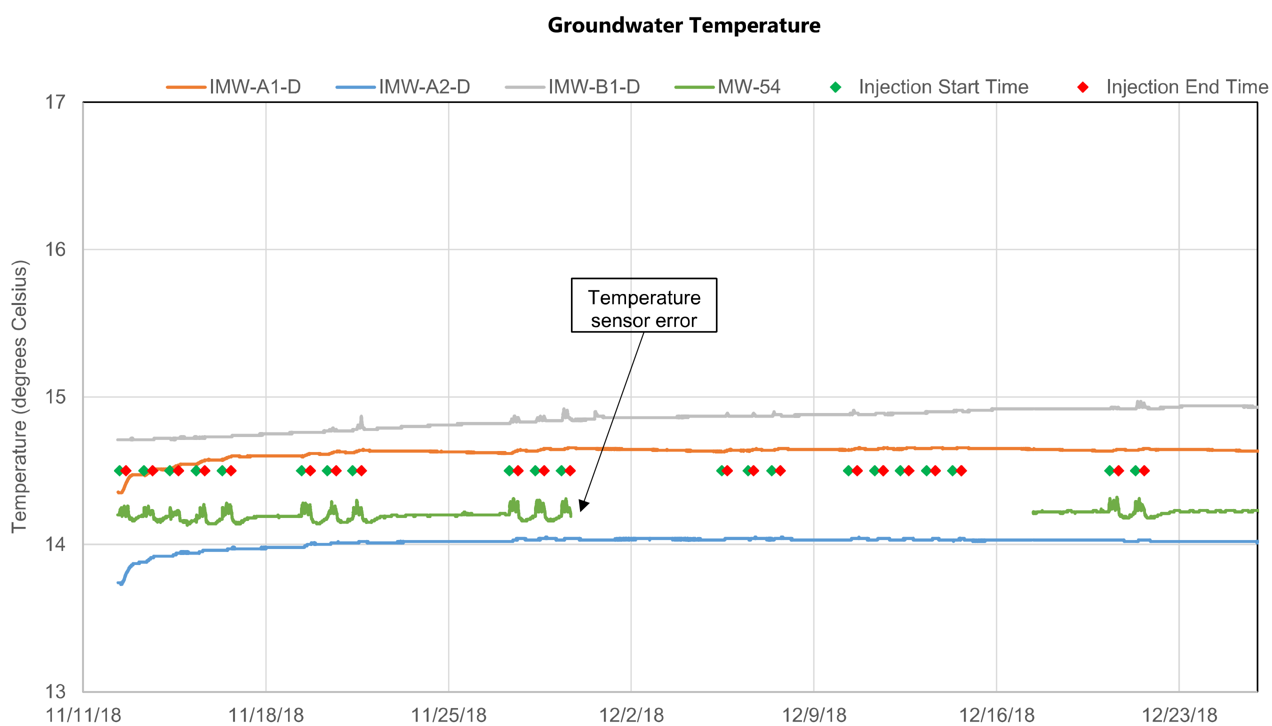
3. pH sensors were calibrated prior to first injection event.

wood.

PHASE 2 SHALLOW WELLS pH AND TEMPERATURE TREND PLOT
Former Rhone-Poulenc Site
Tukwila, WA

| | |
|---|---|
| By: WMY | Figure 38 |
| Project No.: 8769 | |
| Date: 4/30/2020 | |




Notes

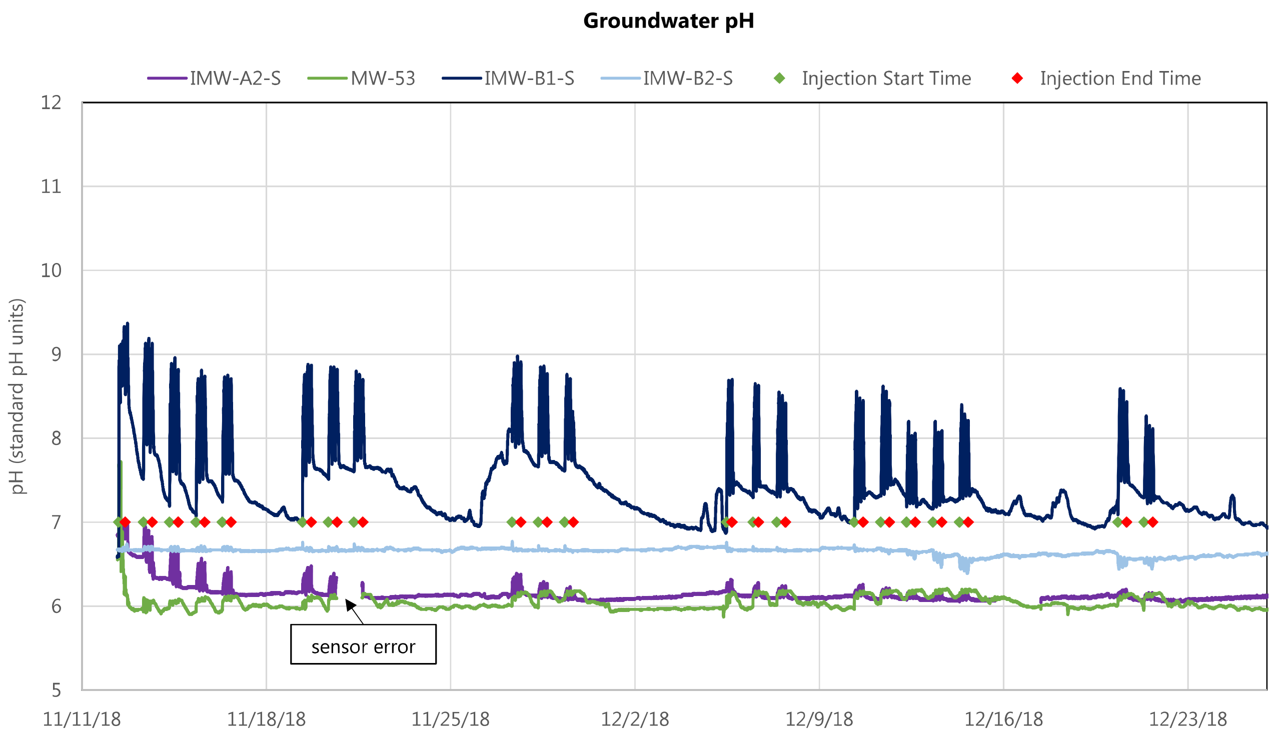
1. pH sensors were calibrated prior to first injection event.

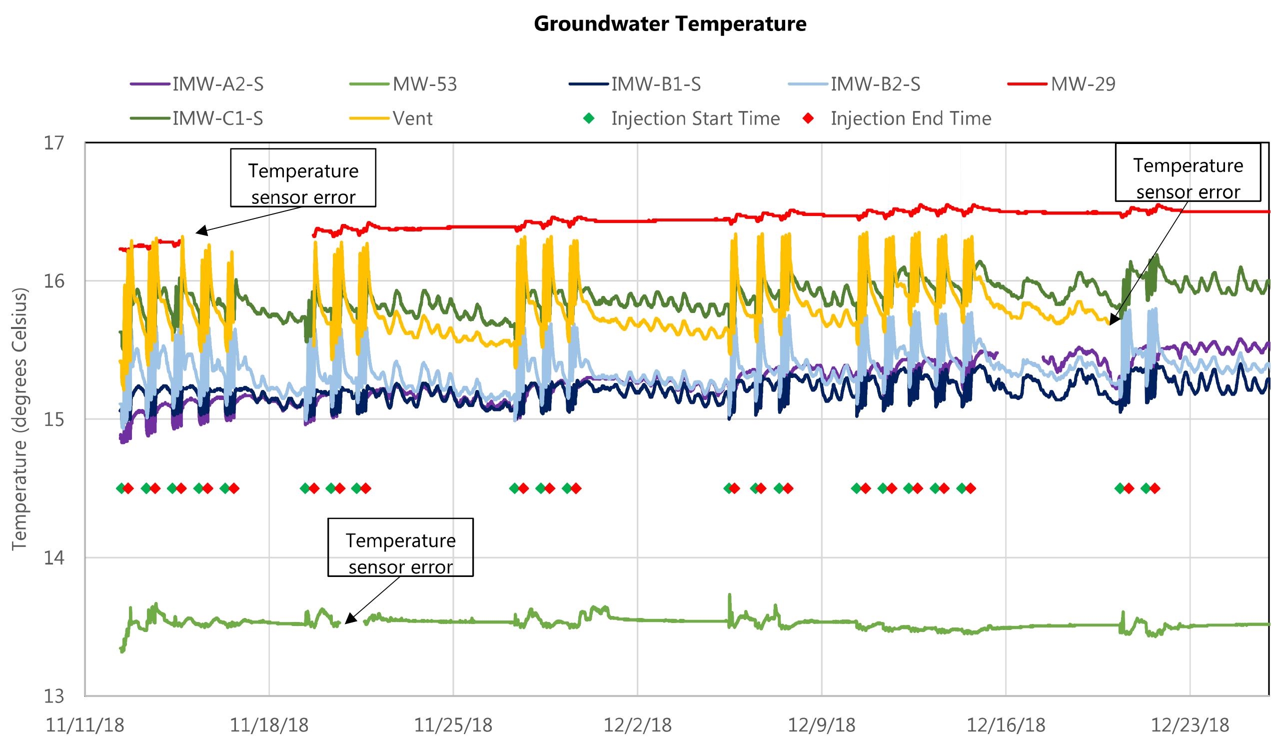
wood.

PHASE 3 DEEP WELLS pH AND TEMPERATURE TREND PLOT
Former Rhone-Poulenc Site
Tukwila, WA

By: WMY
Project No.: 8769
Date: 4/30/2020

Figure 39



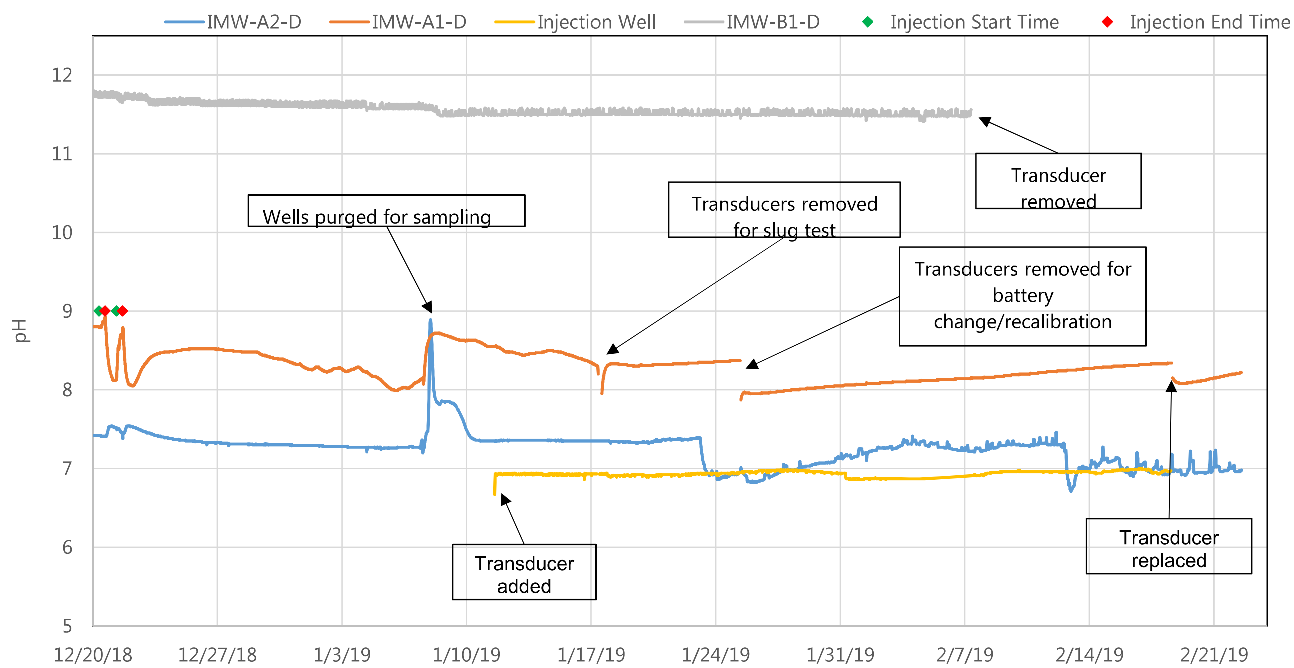




Notes

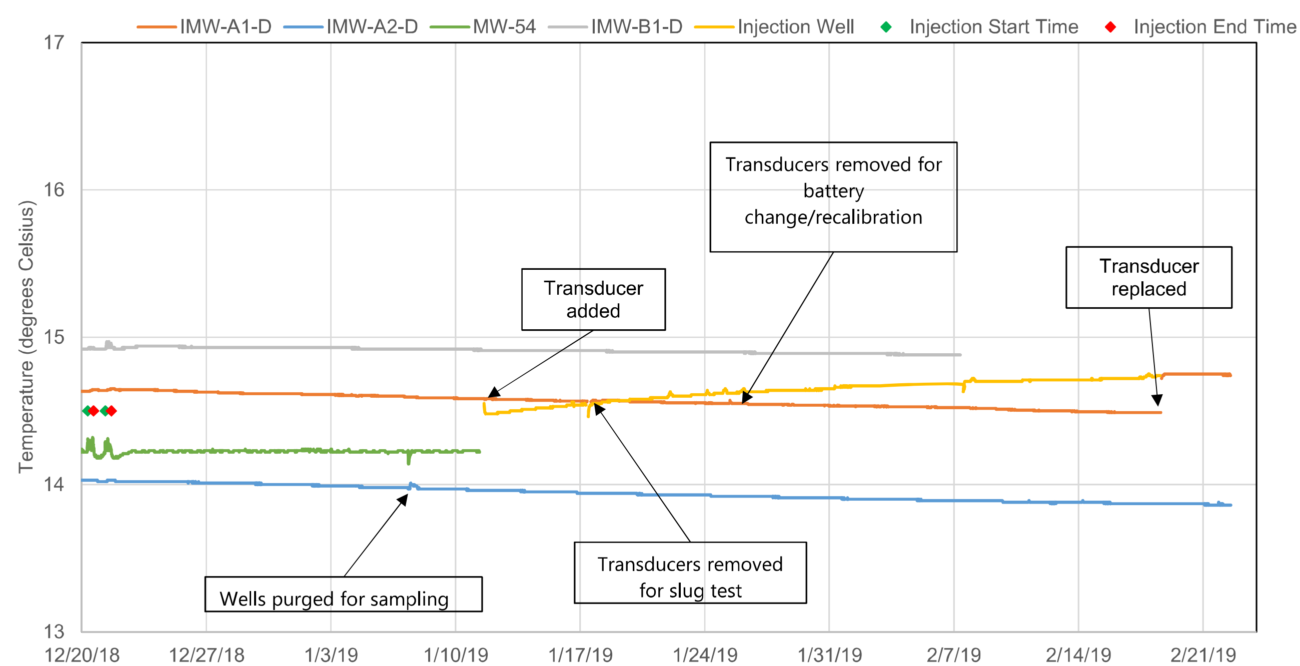
1. pH sensors were calibrated prior to first injection event.

| | | |
|---|---|---|
| wood. | PHASE 3 SHALLOW WELLS pH AND TEMPERATURE TREND PLOT<br>Former Rhone-Poulenc Site<br>Tukwila, WA | |
| | By: WMY<br>Project No.: 8769<br>Date: 4/30/2020 | Figure 40 |

## Groundwater pH




## Groundwater Temperature

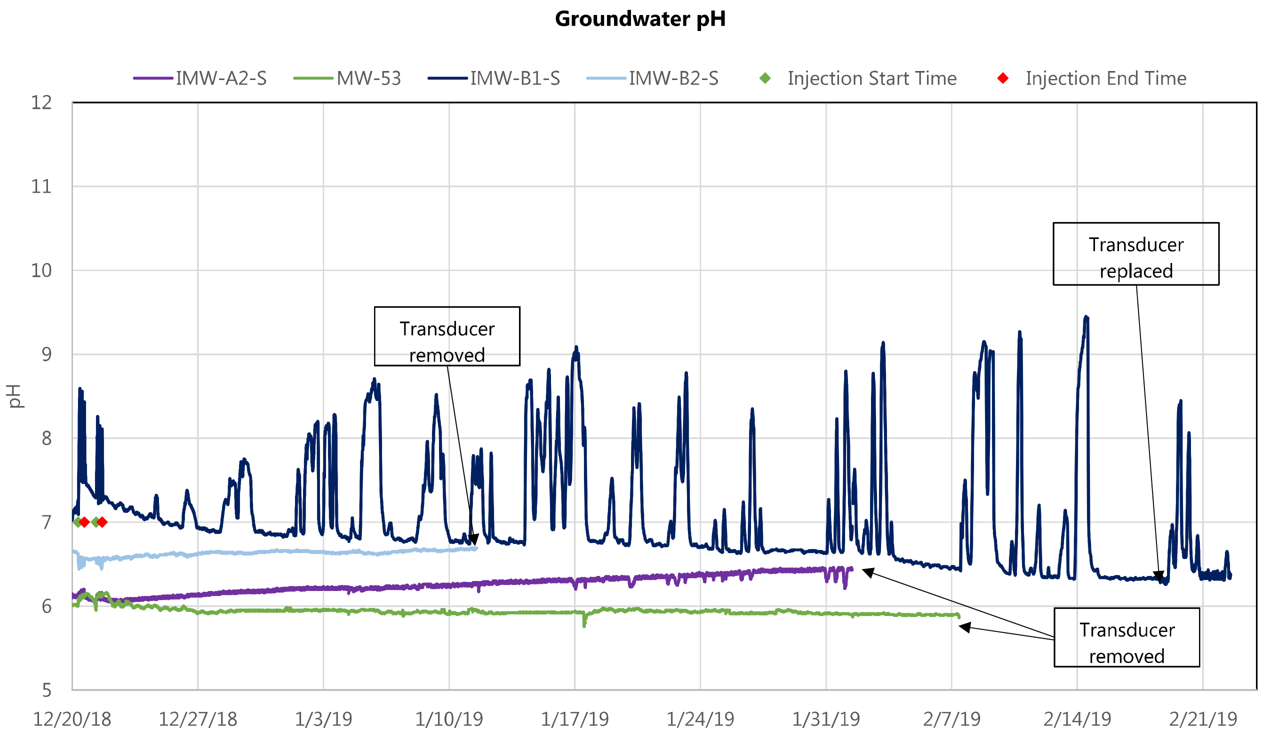


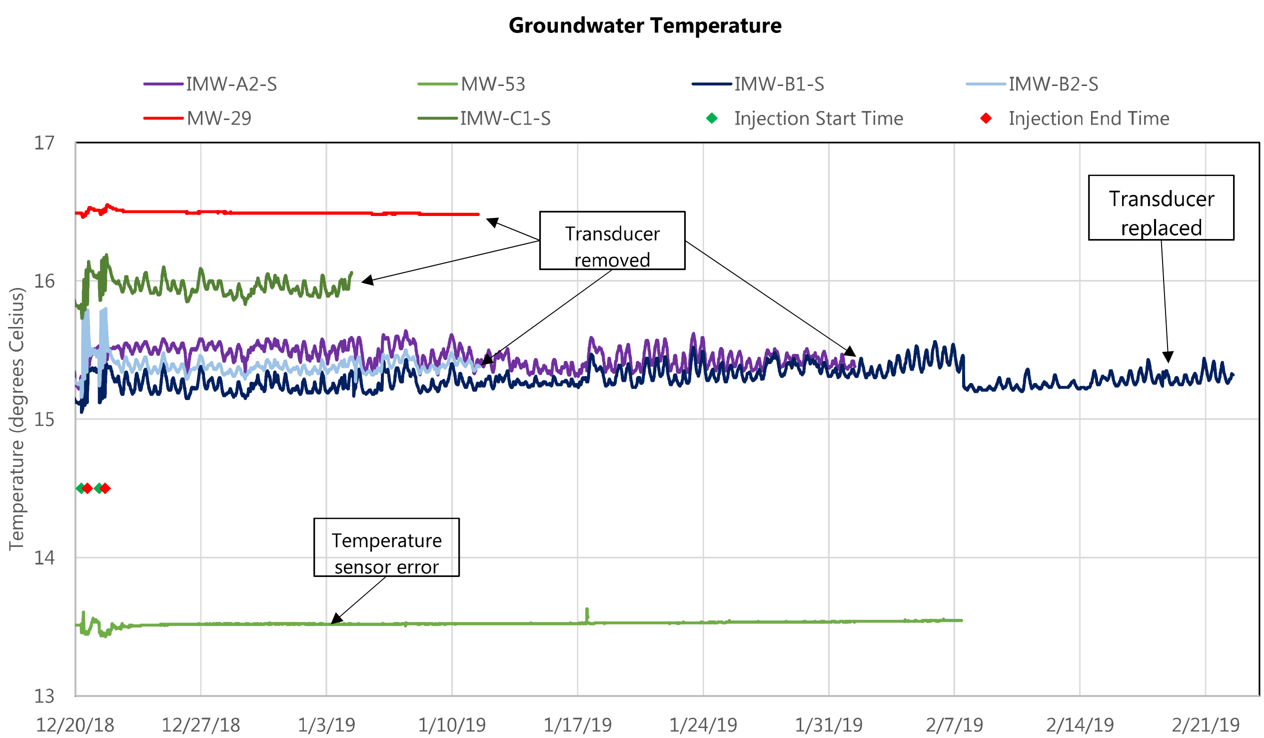

Notes

1. pH sensors were calibrated prior to first injection event.

PHASE 4 DEEP WELLS pH AND TEMPERATURE TREND PLOT
Former Rhone-Poulenc Site
Tukwila, WA

| | |
|---|---|
| By: WMY | Figure 41 |
| Project No.: 8769 | |
| Date: 4/30/2020 | |




Notes

1. pH sensors were calibrated prior to first injection event.

| | | |
|---|---|---|
| wood. | PHASE 4 SHALLOW WELLS pH AND TEMPERATURE TREND PLOT<br>Former Rhone-Poulenc Site<br>Tukwila, Wa | |
| | By: WMY<br>Project No.: 8769<br>Date: 4/30/2020 | Figure 42 |

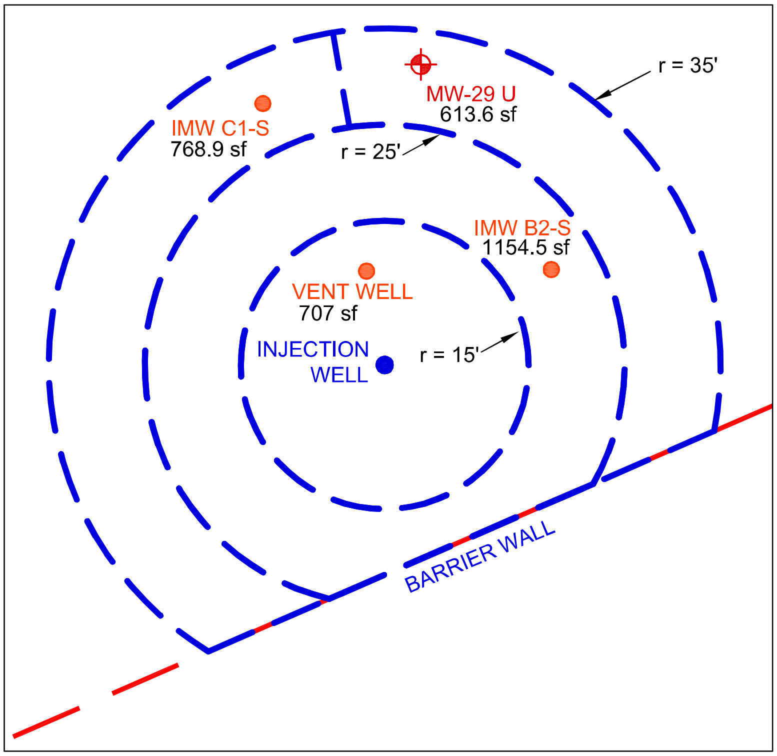
Plot Date: 08/29/18 - 3:21pm, Plotted by: mike.stenberg
Drawing Path: S:\8769_2006\130_CMS WorkPlan 2018\, Drawing Name: FRP_Groundwater Zones 082918.dwg

NOTE:
REPRESENTATIVE GROUNDWATER ZONES WERE DEFINED BY ASSUMING THAT GROUNDWATER CAN BE REPRESENTED BY THE SAMPLING RESULTS OF THE NEAREST REPRESENTATIVE OBERVATION WELL. CROSS SECTION AREAS FOR EACH ZONE ARE LISTED BELOW EACH WELL LABEL.

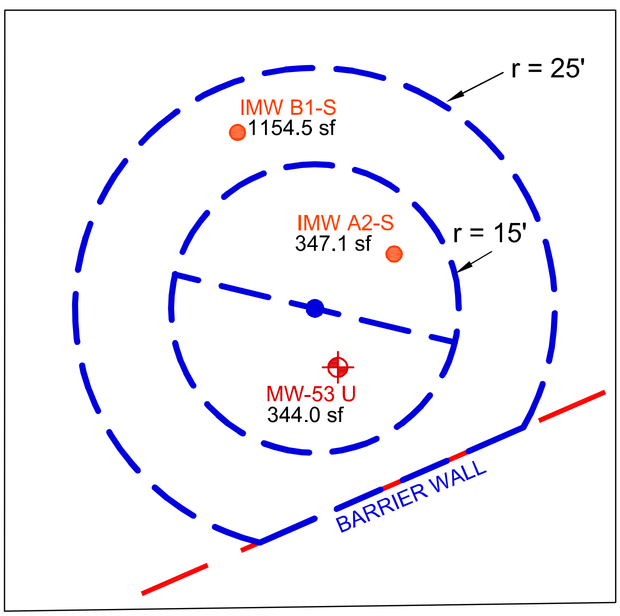
## EXPLANATION

| | |
|---|---|
| IMW A1 | $CO_2$ INJECTION MONITORING WELL |
| | $CO_2$ INJECTION VENT WELL |
| MW-45 L | MONITORING WELL |

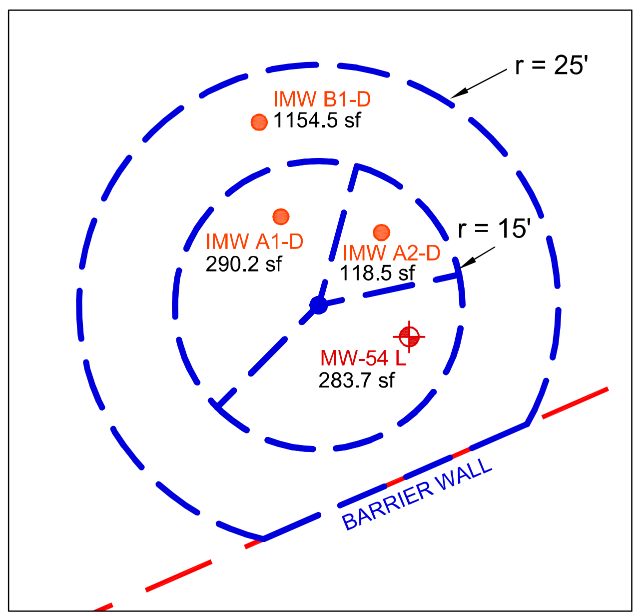
16'-25' bgs

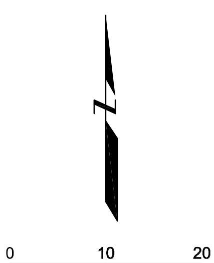



25'-40' bgs




40'-50' bgs



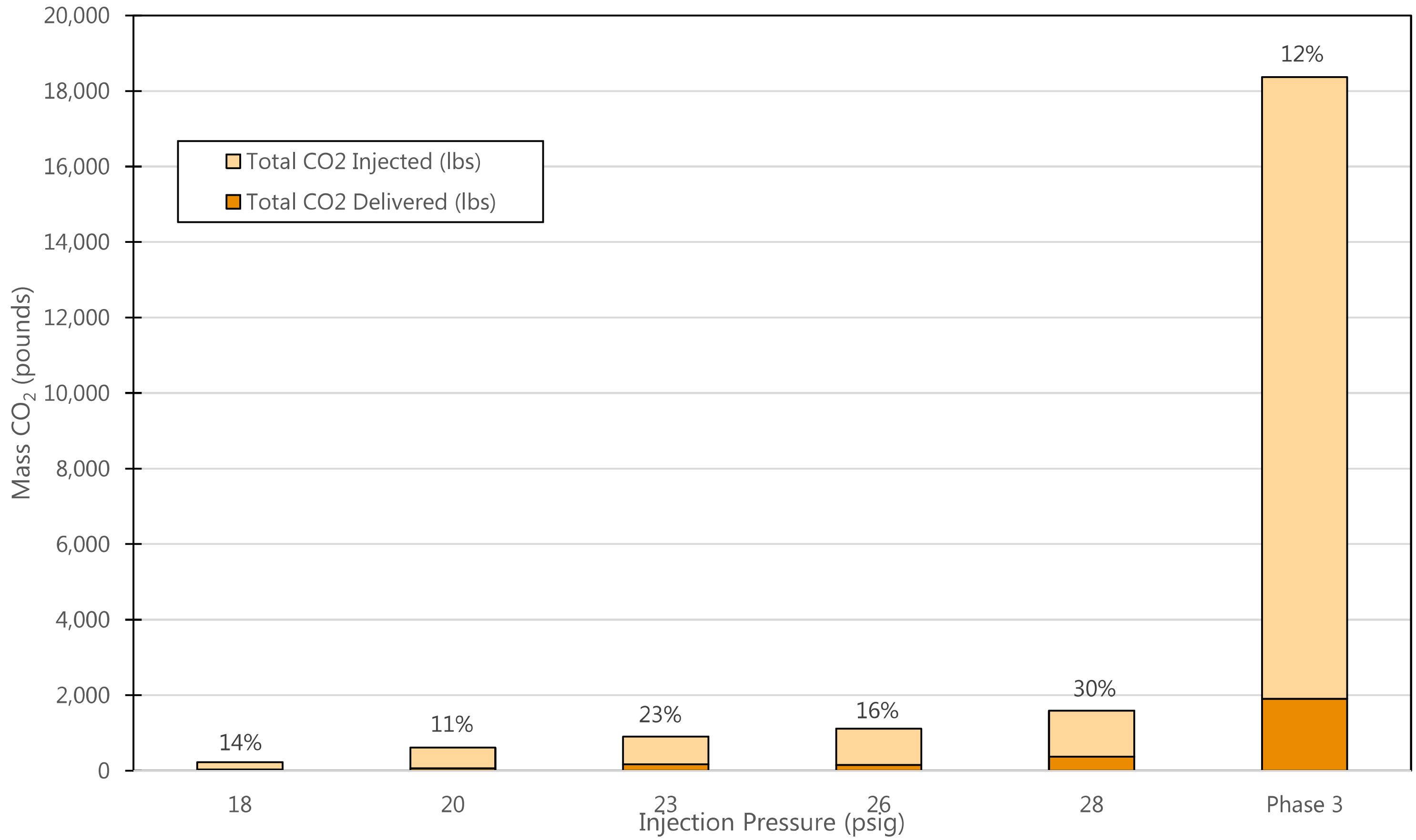




APPROXIMATE SCALE IN FEET

wood.

$CO_2$ UTILIZATION
GROUNDWATER ZONES
Former Rhone-Poulenc Site
Tukwila, Washington

| By: APS | Date: 08/29/18 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | Figure 43 |




Notes

1. Total $CO_2$ injected was calculated from changes in tank level during Phase 1 injection events and from totalizer readings during Phase 3 injection events.

2. Total $CO_2$ delivered was calculated using dissolved total inorganic carbon data from grab samples collected before and after each injection.

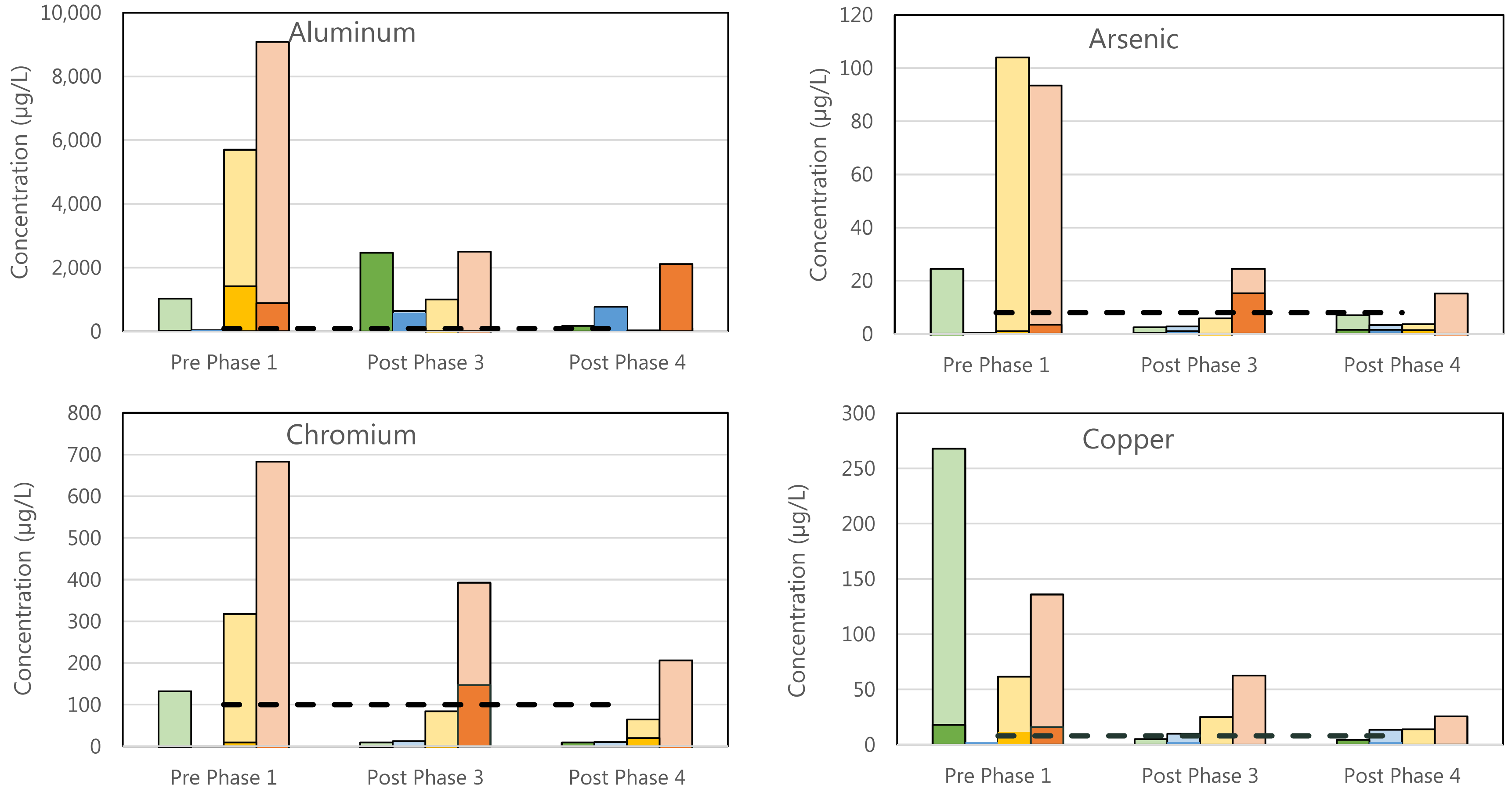
3. Utilization efficiencies are shown in parathensis above bar for each injections.

wood.

$CO_2$ UTILIZATION EFFICIENCY
Former Rhone-Poulenc Site
Tukwila, WA

By: WMY
Project No.: 8769
Date: 5/1/2020

Figure 44




Legend

- Injection Well - Solid
- IMW A1-D - Solid
- MW-54 - Solid
- MW-53 - Solid
- Injection Well - Dissolved
- IMW A1-D - Dissolved
- MW-54 - Dissolved
- MW-53 - Dissolved
- Preliminary Remediation Goal

µg/L = microgram per liter

Notes

1. If the dissolved concentration exceeded the total concentration, only the dissolved value was presented.
2. All undetected values were replaced with 1/2 the detection limit.
3. The total concentration of an analyte is the sum of the solid and dissolved phase.
4. Preliminary remediation goals are from the CMS Work Plan (AMEC 2014).

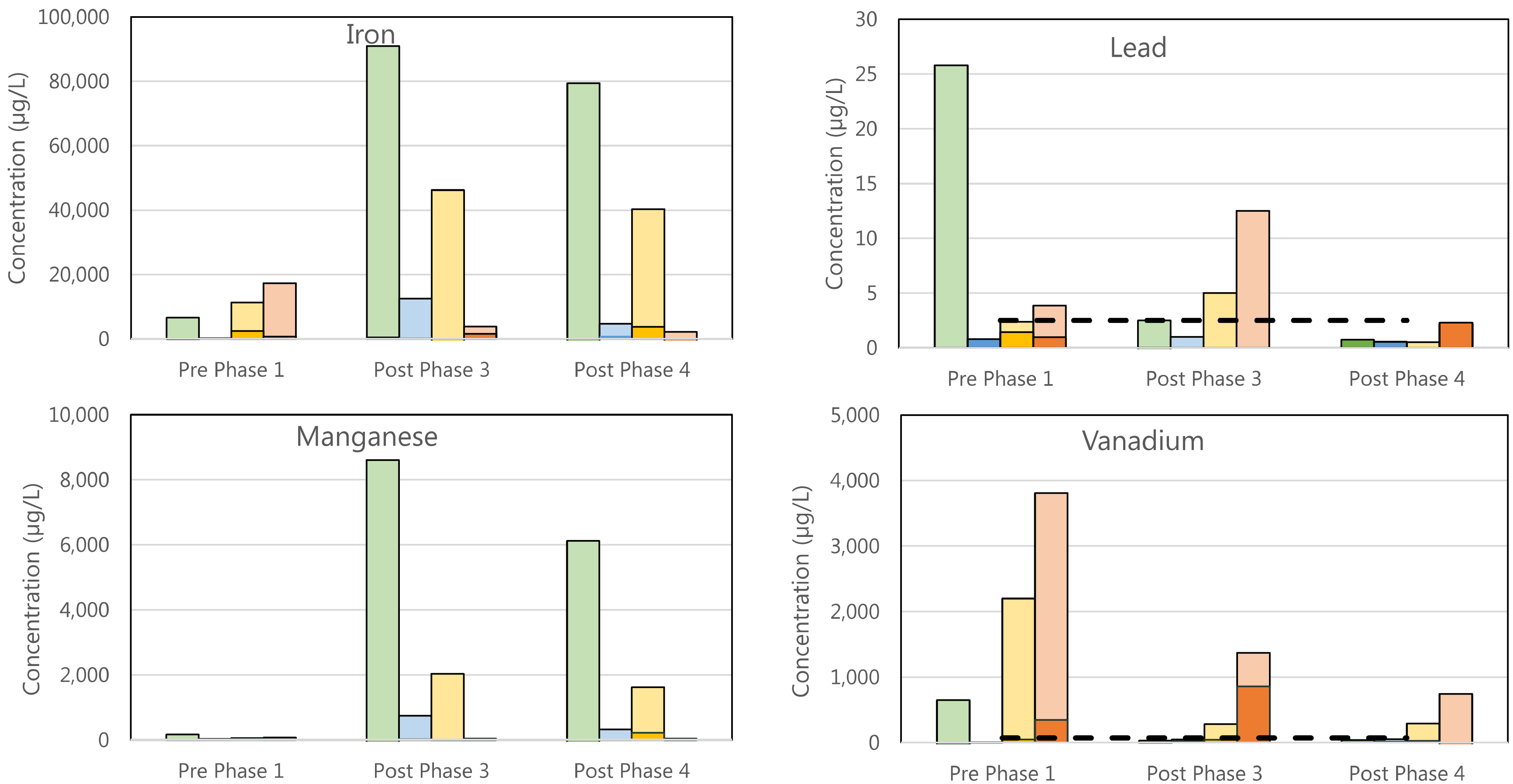
wood.

GROUNDWATER CHEMISTRY CHANGES

Former Rhone-Poulenc Site
Tukwila, WA

By: WY
Project No.: 0087690050
Date: 05/1/2020

Figure 45




Legend
Injection Well - Solid
IMW A1-D - Solid
MW-54 - Solid
MW-53 - Solid
Injection Well - Dissolved
IMW A1-D - Dissolved
MW-54 - Dissolved
MW-53 - Dissolved
Preliminary Remediation Goal
µg/L = microgram per liter

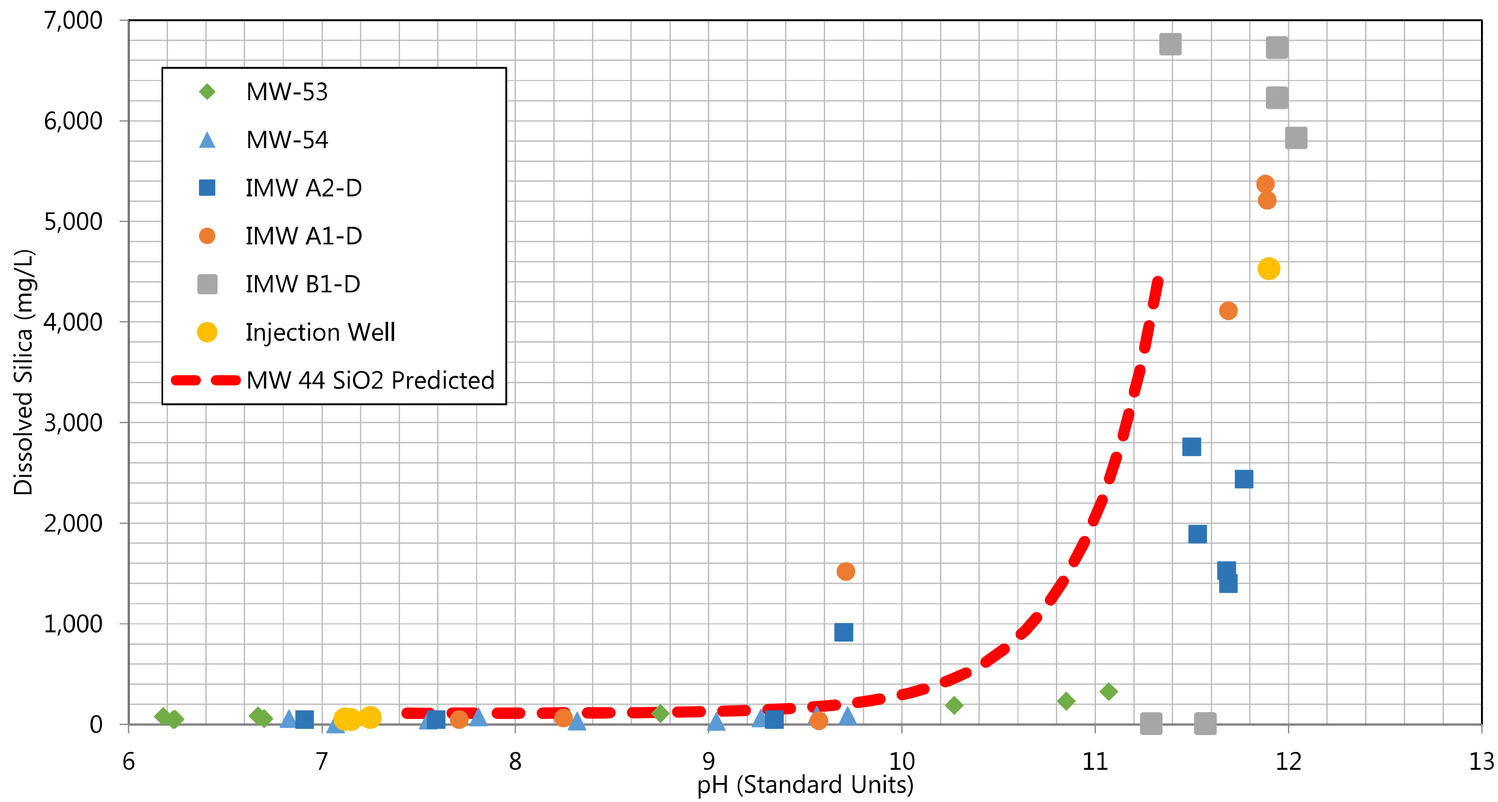
Notes
1. If the dissolved concentration exceeded the total concentration, only the dissolved value was presented.
2. All undetected values were replaced with 1/2 the detection limit.
3. The total concentration of an analyte is the sum of the solid and dissolved phase.
4. Preliminary remediation goals are from the CMS Work Plan (AMEC 2014).

wood.

GROUNDWATER CHEMISTRY CHANGES

Former Rhone-Poulenc Site
Tukwila, WA

| | |
|---|---|
| By: WY | Figure 46 |
| Project No.: 0087690050 | |
| Date: 05/1/2020 | |




Abbreviations

mg/L = milligrams per liter

Notes

1. "MW 44 $SiO_2$ Predicted" is the results of equilibrium modeling of MW-44.

2. $SiO_2$ values for IMW-A1-D and IMW-B1-D for injection events 1 and 2 were both less than 800 mg/L even though the sample pH was greater than 10 SU. These values were excluded from the figure.

wood.

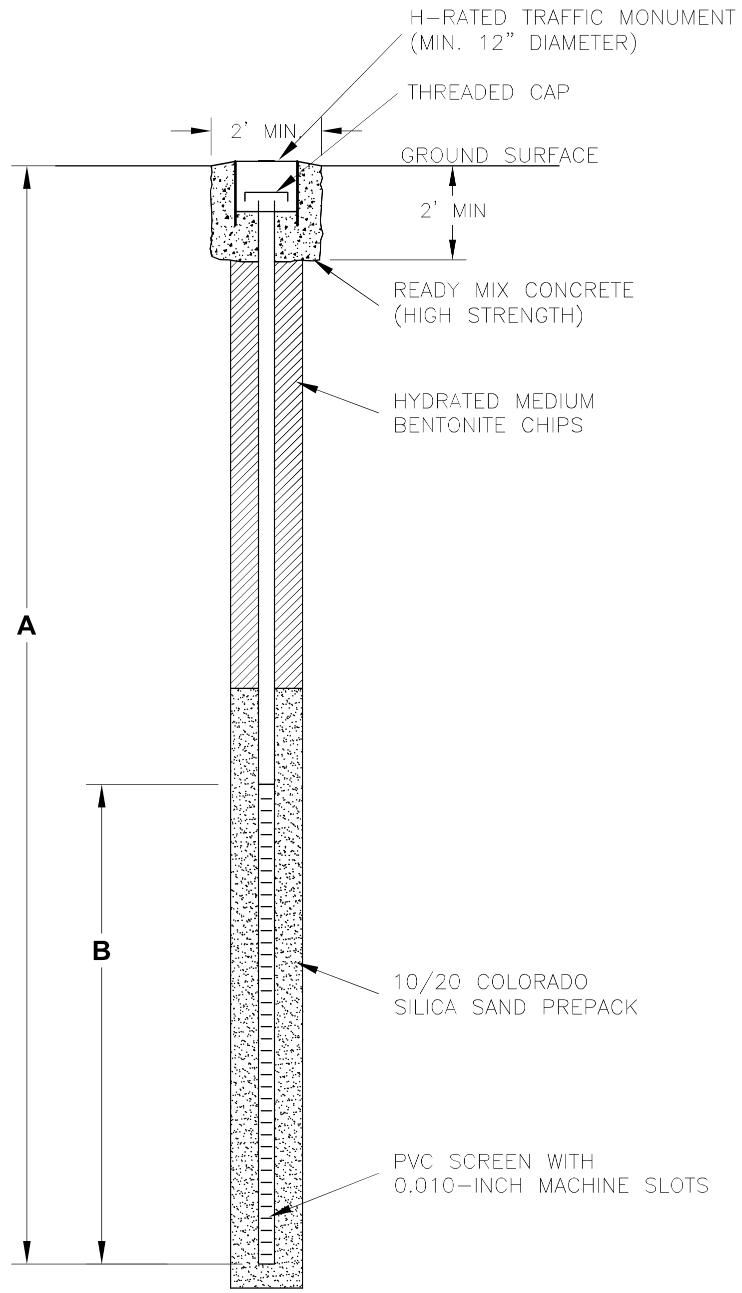
DISSOLVED SILICA VERSUS pH IN $CO_2$ INJECTION AREA

Former Rhone Poulenc Site
Tukwila, WA

By: WMY
Project No.: 8769
Date 5/5/2020

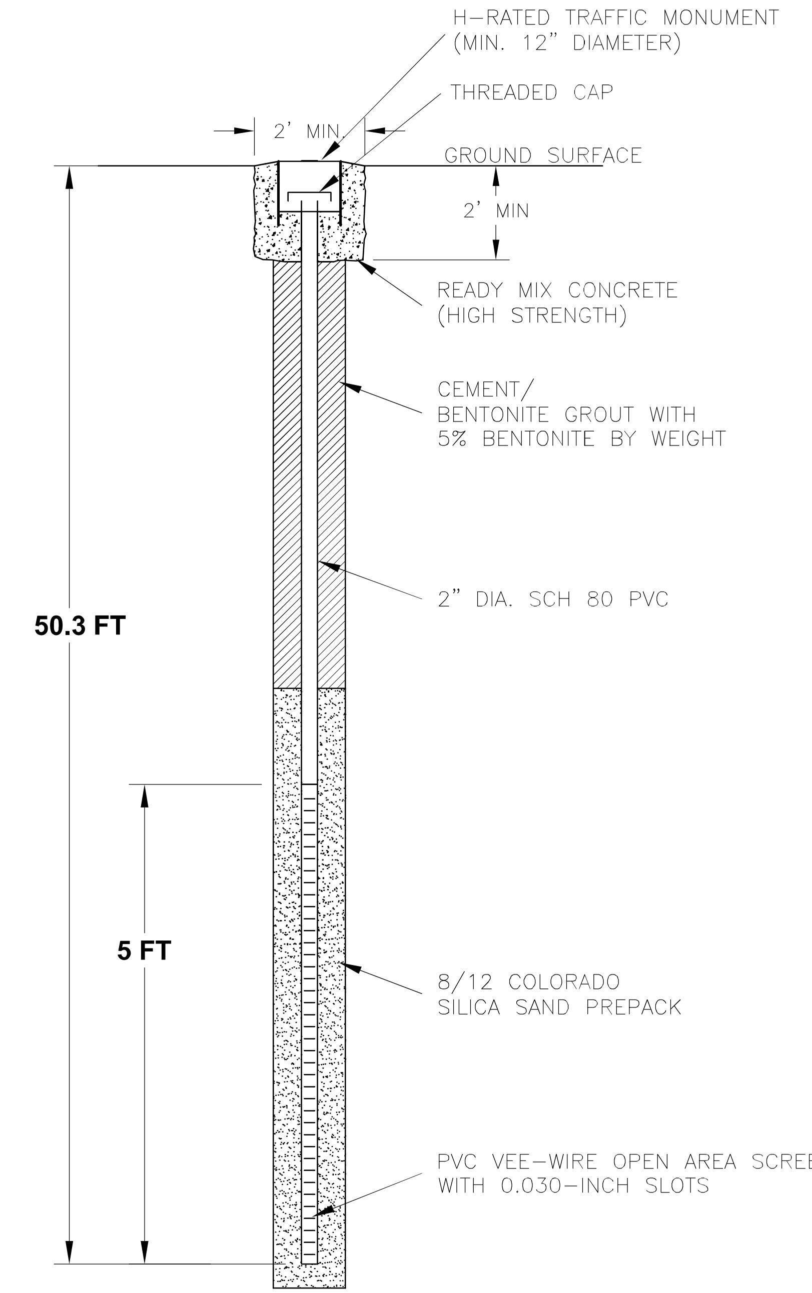
Figure 47

# Drawings




1 OBSERVATION / VENT WELL DETAIL
NOT TO SCALE

| PILOT STUDY NEW OBSERVATION WELLS APPROXIMATE WELL DIMENSIONS (FT) | | | |
|---|---|---|---|
| **WELL ID** | **A** | **B** | **CASING** |
| IMW A1-D | 49.9 | 5 | 2" DIA SCH 80 PVC |
| IMW B1-S | 35.2 | 10 | 2" DIA SCH 80 PVC |
| IMW B1-D | 49.9 | 5 | 2" DIA SCH 80 PVC |
| IMW C1-S | 27.8 | 10 | 2" DIA SCH 80 PVC |
| IMW A2-S | 35.4 | 10 | 2" DIA SCH 80 PVC |
| IMW A2-D | 49.9 | 5 | 2" DIA SCH 80 PVC |
| IMW B2-S | 27.3 | 10 | 2" DIA SCH 80 PVC |
| VENT WELL | 25.2 | 15.2 | 2" DIA SCH 40 PVC |




2 INJECTION WELL DETAIL
NOT TO SCALE

NOTES:

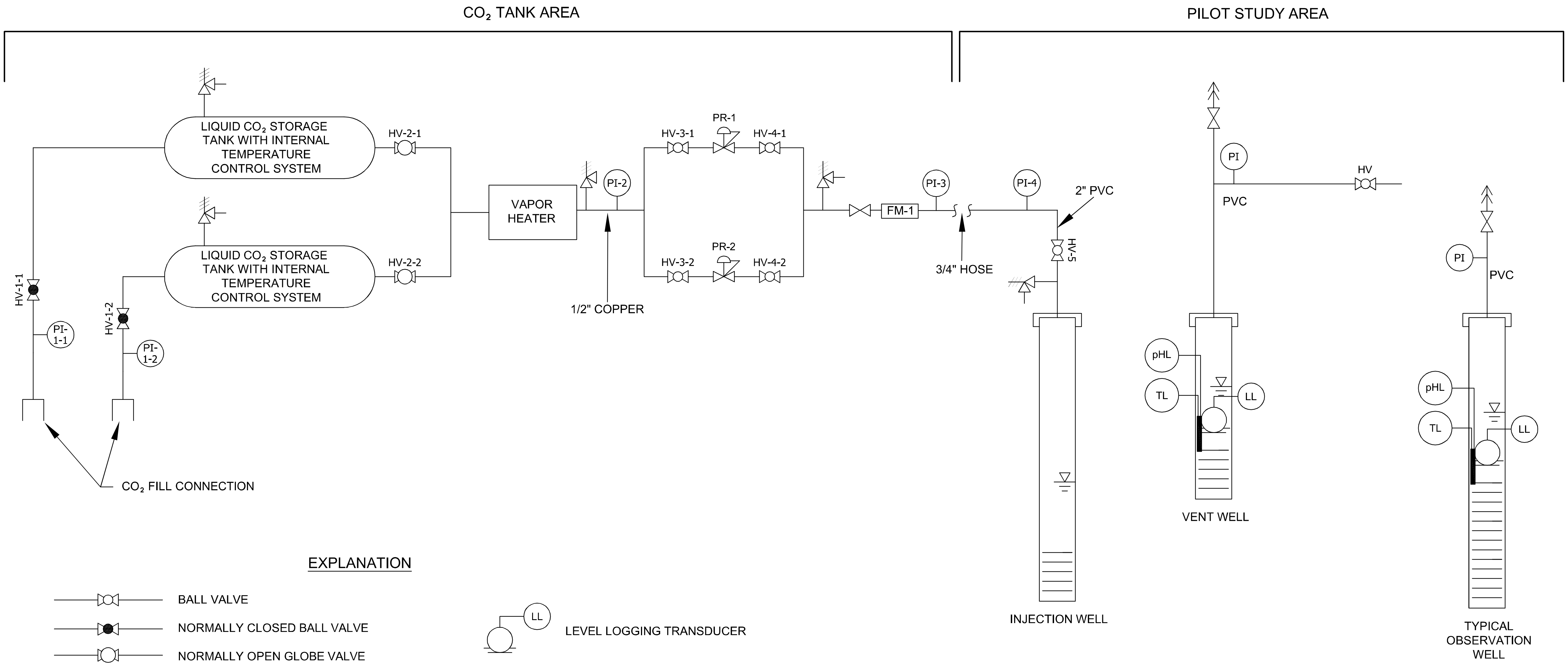
1. WELL DEPTHS AND SCREEN INTERVALS ARE FINAL DEPTH BASED ON FIELD OBSERVATIONS.

2. THE DEPTH OF INJECTION WELL SAND PACK ABOVE THE SCREEN WAS DETERMINED IN THE FIELD BASED ON THE OBSERVED LOCATION OF THE SILTY SAND ZONE.

wood.

PROPOSED PILOT STUDY WELL DETAILS
Former Rhone-Poulenc Site
Tukwila, Washington

| By: APS | Date: 5/14/20 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | DRAWING 1 |




## EXPLANATION

- BALL VALVE
- NORMALLY CLOSED BALL VALVE
- NORMALLY OPEN GLOBE VALVE
- SAMPLE PORT
- PRESSURE RELIEF VALVE
- REGULATED SIDE PRESSURE REGULATING CONTROL VALVE
- QUICK CONNECT CAM-LOCK FITTING
- THREADED OR GLUED CAP
- FM FLOW METER
- HV = HAND VALVE
- PR = PRESSURE REGULATOR
- LL LEVEL LOGGING TRANSDUCER
- PI PRESSURE INDICATOR
- pHL pH LOGGER
- TL TEMPERATURE LOGGER
- FLOW CONTROL VALVE

wood.

$CO_2$ INJECTION SYSTEM
PROCESS AND INSTRUMENTATION DIAGRAM
Former Rhone-Poulenc Site
Tukwila, Washington

| By: APS | Date: 05/14/20 | Project No. 08769 |
|---|---|---|
| Wood Environment & Infrastructure Solutions, Inc. | | P&ID 02 |

# Appendix A

| | | | |
|---|---|---|---|
| PROJECT: FRP $CO_2$ Pilot study | LOG OF BORING: Injection well | | |
| BORING LOCATION: | ELEVATION AND DATUM: | | |
| DRILLING CONTRACTOR: Cascade Drilling, L.P. | DATE STARTED: 2/6/18 | DATE COMPLETED: 2/6/18 | |
| DRILLING METHOD: Sonic drilling | TOTAL DEPTH: 50 | MEASURING POINT: ground surface | |
| DRILLING EQUIPMENT: TSI compact crawler 150 | DEPTH TO FIRST WATER 19.5 | DEPTH TO FREE WATER | |
| SAMPLING METHOD: | CASING: See well const. log | SCREEN INTERVAL: See well const. log | |
| BOREHOLE DIAMETER: 6" | LOGGED BY: K. Black | | |

HAMMER TYPE/SYSTEM: NA

| DEPTH | Interval | Run # | PID | DESCRIPTION<br>NAME (USCS Symbol): color, mottling, moisture, percent distribution of coarse and fine grained material, angularity, plasticity and dilatency (if predominately fine grained), relative density/conitency, cementation, structure, minerals and alteration, odor, geologic interpretation (eg. Native Soil) | ADDITIONAL INFORMATION |
|---|---|---|---|---|---|
| | | | 0.0 | asphalt<br>SILTY SAND WITH GRAVEL (SM): very dark grayish brown (2.5Y 3/2); moist; 65% predominately fine to medium sand; 25% gravel fine to coarse (5.5cm largest gravel) subangular; (fill) | |
| | | | 0.0 | | 1.25 |
| 5 | | 1 | | POORLY GRADED SAND (SP): very dark gray (5Y 3/1); moist; 95% predominately fine sand; 5% silt fines; 0.5"-1" silty sand inclusions<br>minor gravel medium subangular 2.5-3'<br>silty sand (SM): olive brown (2.5Y 4/3), moist; 80% fine sand, 20% silt; | |
| 10 | | | 0.0 | silty sand (SM): dark gray (5Y 4/1) w/ olive brown mottling; 75% fine sand 25% silt; w/ interbedded dark gray (5Y 4/1) poorly graded fine sand (95% fine sand 5% silt) layers; | |
| | | | 0.0 | POORLY GRADED SAND (SP): very dark gray (5Y 3/1); moist; 95% fine ~~[illegible]~~ 5% silt)<br>3" silty SAND (SM) layer<br>~~[illegible]~~ becomes fine to medium sand @ 13.5' | |
| 15 | | 2 | 0.0 | 3" silty SAND (SM) olive brown mottling | |
| 1.5 bags | | | | | |
| 20 | | | 0.0 | becomes wet, poorly graded fine sand<br>3" silty SAND SM dark gray inclusion | |
| 25 | | 3 | 0.0 | | |
| | | | | moderately decomposed wood | |
| | | | 0.0 | | |
| 30 | | | | | |

| PROJECT: | | | | | LOG OF BORING: Injection well | |
|---|---|---|---|---|---|---|
| DEPTH | Interval | Run | PID | | **DESCRIPTION**<br>NAME (USCS Symbol): color, mottling, moisture, percent distribution of coarse and fine grained material, angularity, plasticity and dilatency (if predominately fine grained), relative density/conitency, cementation, structure, minerals and alteration, odor, geologic interpretation (eg. Native Soil) | ADDITIONAL INFORMATION |
| | | | 0.0 | | same as above: poorly graded sand (SP) | |
| 35 | | 4 | 3.9 | | | |
| | | | 1.5 | | silty SAND inclusions | |
| 40 | | | | | | |
| | | | 0.7 | | 9" poorly graded sand w/ gravel (SP): dark gray (5Y 3/1); wet; 90% med to coarse sand, 10% fine to med gravel, subangular | |
| | | 5 | | | Silty SAND (SM): dark gray (2.5Y 4/1); wet; 60% fine sand, 40% medium plastic silt | |
| 45 | | | 2.1 | | Silty SAND (SM): dark gray (2.5Y 4/1); wet; 75% fine sand, 25% medium plastic silt; organic odor; w/ lenses of medium plastic firm silt | |
| | | | 2.2 | | | |
| 50 | | | | | terminate boring @ 50' bgs | |
| | | | | | Set well - see well const. log | |
| 55 | | | | | Ecology well # BKF 247 | |
| 60 | | | | | | |
| 65 | | | | | | |

Project No. | Page __ of __

*page 1*

| PROJECT: FRP $CO_2$ Injection | LOG OF BORING: IMW B2-S |
|---|---|

| DEPTH | Interval Recovery | PID | | | DESCRIPTION (Cascade Direct Push; start 2/9/18) NAME (USCS Symbol): color, mottling, moisture, percent distribution of coarse and fine grained material, angularity, plasticity and dilatency (if predominately fine grained), relative density/conitency, cementation, structure, minerals and alteration, odor, geologic interpretation (eg. Native Soil) | ADDITIONAL INFORMATION (complete 2/9/18) |
|---|---|---|---|---|---|---|
| 5 | No Samples | | | | | |
| 10 | | | | | | |
| 15 | | 0.0 | | | poorly graded sand (SP): Black (2.5Y 2.5/1) fine to medium sand, 5% silt, trace ~~coarse sand~~ fine gravel, lenses of silty sand (70% fine sand, 30% silt) wet @ 16' | no plastic |
| 20 | | 0.0 | | | very dark grayish brown (2.5Y 3/2) silty sand lens | brownish black weed like rootbed |
| 25 | | | | | no silt lenses | |
| 27.7 | | | | | ~~[illegible]~~ | |
| 30 | | | | | boring terminated @ 27.5' bgs; ~~FF-25~~ | |

| Project No. | | Page __ of __ |
|---|---|---|

| PROJECT: FRP $CO_2$ injection Study | LOG OF BORING: 1MW-A1-D | |
|---|---|---|
| BORING LOCATION: | ELEVATION AND DATUM: | |
| DRILLING CONTRACTOR: Cascade | DATE STARTED: 2/7/18 | DATE COMPLETED: 2/7/18 |
| DRILLING METHOD: direct push | TOTAL DEPTH: 50 | MEASURING POINT: |
| DRILLING EQUIPMENT: Geo probe 7822DT | DEPTH TO FIRST WATER: Not in screen interval | DEPTH TO FREE WATER |
| SAMPLING METHOD: Macrocore w/liner | CASING: see well const. log | SCREEN INTERVAL: |
| BOREHOLE DIAMETER: 2 1/4 pilot ; 3 3/4" casing | LOGGED BY: K. Black | |
| HAMMER TYPE/SYSTEM: NA | | |

| DEPTH | % core/interval | PID | | | DESCRIPTION<br>NAME (USCS Symbol): color, mottling, moisture, percent distribution of coarse and fine grained material, angularity, plasticity and dilatency (if predominately fine grained), relative density/conitency, cementation, structure, minerals and alteration, odor, geologic interpretation (eg. Native Soil) | ADDITIONAL INFORMATION |
|---|---|---|---|---|---|---|
| 10 | No samples collected | | | | | |
| 20 | | | | | | |
| 30 | | | | | | |
| | | 0.0 | | | Poorly graded Sand (SP): Black (5Y 2.5/1); wet 100% fine to medium sand predominately medium sand, trace silt | |
| 40 | | | | | Poorly graded sand (SP): Black (5Y 2.5/1); 100% fine sand trace silt; | |
| | | 0.6 | | | | |
| | | 2.7 | | 44.5 | Sandy silt (ML): Black (5Y 2.5/1); wet; 85% medium plastic silt w/ 15% fine sand. some organic odor<br>Silty sand (SM): Black (5Y 2.5/1); wet; 70% fine sand 30% medium plastic silt, some roots moderately decomposed w/ medium plastic, fine sandy silt lenses | brown root beer groundwater w/in casing, saturated |
| 50 | | | | | Boring terminated @ 50'<br>see well const. log<br>Ecology ID BKF 248 | |

| Project No. | | Page 1 of ___ |
|---|---|---|

| | |
|---|---|
| PROJECT: FRP $CO_2$ injection Study | LOG OF BORING: IMW A2-D |
| BORING LOCATION: | ELEVATION AND DATUM: |
| DRILLING CONTRACTOR: Cascade Drilling | DATE STARTED: 2/9/18 / DATE COMPLETED: 2/9/18 |
| DRILLING METHOD: direct push | TOTAL DEPTH: 50' / MEASURING POINT: ground surface |
| DRILLING EQUIPMENT: Geoprobe 7822DT | DEPTH TO FIRST WATER: no samples from water interval / DEPTH TO FREE WATER: |
| SAMPLING METHOD: macrocore w/ liner | CASING: / SCREEN INTERVAL: |
| BOREHOLE DIAMETER: 2 1/4" casing w/ 2" liner; overdrill for well w/ 3 3/4" casing | LOGGED BY: K. Black |
| HAMMER TYPE/SYSTEM: NA | |

| DEPTH | interval/recovery | PID | | | DESCRIPTION<br>NAME (USCS Symbol): color, mottling, moisture, percent distribution of coarse and fine grained material, angularity, plasticity and dilatency (if predominately fine grained), relative density/conitency, cementation, structure, minerals and alteration, odor, geologic interpretation (eg. Native Soil) | ADDITIONAL INFORMATION |
|---|---|---|---|---|---|---|
| 10 | | | | | | |
| 20 | No samples | | | | | |
| 30 | | | | | | |
| | | 0.0 | | | Poorly graded sand (SP): Black (2.5Y 2.5/1); wet; 100% fine to medium sand, trace silt; nodules of medium plastic silt | |
| 40 | | | | | ↓ becomes finer ~~85%~~ sand, 15% silt w/ organic odor | |
| | | 0.3 | | | | |
| | | 1.3 | | | | Brown colored water |
| 50 | | | | | Silty sand (SM): Black (2.5Y 2.5/1); wet; 75% fine sand, 25% medium plastic silt; w/ lenses of medium plastic silt. | |
| | | | | | Boring terminated @ 50' to set well | |
| | | | | | BKF-253 | |

| | |
|---|---|
| PROJECT: FRP $CO_2$ Injection | LOG OF BORING: IMW-31S |
| BORING LOCATION: | ELEVATION AND DATUM: |
| DRILLING CONTRACTOR: Cascade | DATE STARTED: 2/7/18 / DATE COMPLETED: 2/7/18 |
| DRILLING METHOD: direct push | TOTAL DEPTH: 35' / MEASURING POINT: ground surface |
| DRILLING EQUIPMENT: Geoprobe | DEPTH TO FIRST WATER: 19 / DEPTH TO FREE WATER: |
| SAMPLING METHOD: macrocore w/ liner | CASING: / SCREEN INTERVAL: |
| BOREHOLE DIAMETER: 2 1/4" pilot; 3 3/4" casing | LOGGED BY: |
| HAMMER TYPE/SYSTEM: NA | |

| DEPTH | recovery interval | PID | | | DESCRIPTION<br>NAME (USCS Symbol): color, mottling, moisture, percent distribution of coarse and fine grained material, angularity, plasticity and dilatency (if predominately fine grained), relative density/conitency, cementation, structure, minerals and alteration, odor, geologic interpretation (eg. Native Soil) | ADDITIONAL INFORMATION |
|---|---|---|---|---|---|---|
| 2 | no samples | | | | | |
| 10 | | | | | | |
| | | | | | poorly graded sand (SP) wet dark gray to very dark gray (2.5Y 4/1 - 3/1) 95% very fine sand 5% silt, w/ silty sand (75% very fine sand, 25% silt) | |
| | | 0.0 | | | poorly graded sand (SP) Black (2.5Y 2.5/1) wet 100% fine sand w/ trace silt (& sandy silt/fine silt lenses ~~[illegible]~~ 03 (90% sand, 10% silt) | |
| 20 | | | | | | |
| | | 0.0 | | | | |
| | | | | | ↓ no sand w/ silt lenses (clean poorly graded sand) | |
| | | 0.0 | | | | |
| 30 | | | | | | |
| | | 0.0 | | | | |
| | | | | | Terminate boring @ 35' | |
| 40 | | | | | Ecology ID BKF-249 | |

| PROJECT: FRP $CO_2$ injection | LOG OF BORING: MW-A2-S | |
|---|---|---|
| BORING LOCATION: | ELEVATION AND DATUM: | |
| DRILLING CONTRACTOR: Cascade | DATE STARTED: 2/9/18 | DATE COMPLETED: 2/9/18 |
| DRILLING METHOD: direct push | TOTAL DEPTH: 35' | MEASURING POINT: ground surface |
| DRILLING EQUIPMENT: Geoprobe 7822DT | DEPTH TO FIRST WATER: no sample from wet interval | DEPTH TO FREE WATER |
| SAMPLING METHOD: | CASING: See well construction log | SCREEN INTERVAL: |
| BOREHOLE DIAMETER: 2 1/4" casing w/ 2" liner; overdrill for well 3 3/4" casing | LOGGED BY: K. Blaer | |
| HAMMER TYPE/SYSTEM: NA | | |

| DEPTH | interval / recovery | PID | | | DESCRIPTION<br>NAME (USCS Symbol): color, mottling, moisture, percent distribution of coarse and fine grained material, angularity, plasticity and dilatency (if predominately fine grained), relative density/conitency, cementation, structure, minerals and alteration, odor, geologic interpretation (eg. Native Soil) | ADDITIONAL INFORMATION |
|---|---|---|---|---|---|---|
| | | | | | asphalt | |
| 2 | no sample | | | | silty sand w/ gravel fill; | direct dump into drum - no sample |
| | | | | | poorly graded sand, gray, - | |
| 10 | | | | | | |
| | no sample | | | | | no sample |
| 20 | | 0.0 | | | poorly graded sand (SP): Black (2.5Y 2.5/1), wet 100% fine to medium sand, trace silt, wet | |
| | | | | | no ↓ w/ nodules of silty sand | |
| | | 0.0 | | | | |
| 30 | | | | | ↓ no silty sand | |
| | full recovery | 0.0 | | | | |
| | | | | | Boring terminated @ 35' | |
| 40 | | | | | ~~BRF-284~~ BKF-254 | |

| | | | |
|---|---|---|---|
| PROJECT: FRP $CO_2$ Injection | | LOG OF BORING: vent well | |
| BORING LOCATION: | | ELEVATION AND DATUM: | |
| DRILLING CONTRACTOR: Cascade | | DATE STARTED: 2/8/18 | DATE COMPLETED: 2/8/18 |
| DRILLING METHOD: Direct push see 2/7/18 logs | | TOTAL DEPTH: 25' | MEASURING POINT: ground surface |
| DRILLING EQUIPMENT: Geoprobe 7822 DT | | DEPTH TO FIRST WATER: 17' | DEPTH TO FREE WATER |
| SAMPLING METHOD: macrocore w/ liner | | CASING: see well const log | SCREEN INTERVAL: |
| BOREHOLE DIAMETER: 2 1/4 pilot, overdrill w/ 3 3/4" casing | | LOGGED BY: K Black | |
| HAMMER TYPE/SYSTEM: NA | | | |

| DEPTH | Interval | PID | | | DESCRIPTION<br>NAME (USCS Symbol): color, mottling, moisture, percent distribution of coarse and fine grained material, angularity, plasticity and dilatency (if predominately fine grained), relative density/conitency, cementation, structure, minerals and alteration, odor, geologic interpretation (eg. Native Soil) | ADDITIONAL INFORMATION |
|---|---|---|---|---|---|---|
| | no sample | | | | | |
| 5 | | | | | poorly graded sand w/ silt (SP-SM): very dark gray (2.5Y 3/1) 90% fine sand, 10% silt w/ silt with sand lenses containing ~ 80% silt, 15% fine sand & silty lenses. dark grayish brown (2.5Y 4/2) moist medium plastic; silt 75% silt, 25% fine sand | moist |
| | | 0.0 | | | | |
| 10 | | | | | | |
| | | 0.0 | | | | |
| | | | | | Poorly grade sand (SP): black (2.5Y 2.5/1): moist 95% fine to medium sand; trace fine gravel 5% silt | |
| 15 | | | | | Poorly graded sand (SP): dark grayish brown (2.5Y 4/2) moist 95% fine sand, 5% silt w/ lenses of sandy silt 75% silt, 25% fine sand; nodules of medium plastic silt w/ sand | |
| | | 0.0 | | | Poorly graded sand (SP): black (2.5Y 2.5/1) wet 95% fine to medium sand, trace fine gravel 5% silt | |
| 20 | | | | | Poorly grade sand (SP): dk grayish brown (2.5Y 4/2), wet, 95% fine sand 5% silt w/ lenses of sandy silt 75% silt, 25 75% silt w/ 25% fine sand, medium plastic silt nodules w/ sand | |
| | | 0.0 | | | Poorly graded sand (SP): black (2.5Y 2.5/1) wet 95% fine to med. sand trace fine gravel 5% silt | |
| 25 | | | | | Terminate boring @ 25' | |
| | | | | | BKF 252 | |

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|---|---|---|---|
| Project No. | | | Page 1 of ___ |

| PROJECT: FRP $CO_2$ injection | LOG OF BORING: IMW-C1-S | |
|---|---|---|
| BORING LOCATION: | ELEVATION AND DATUM: | |
| DRILLING CONTRACTOR: Cascade | DATE STARTED: 2/8/18 | DATE COMPLETED: 2/8/18 |
| DRILLING METHOD: Direct push | TOTAL DEPTH: 27.5 | MEASURING POINT: |
| DRILLING EQUIPMENT: Geoprobe 7822 DT same as 2/7 | DEPTH TO FIRST WATER: 20' | DEPTH TO FREE WATER |
| SAMPLING METHOD: Macrocore w/ liner | CASING: See well const. log | SCREEN INTERVAL: |
| BOREHOLE DIAMETER: 2 1/4" pilot; 3 3/4" casing | LOGGED BY: K. Black | |
| HAMMER TYPE/SYSTEM: NA | | |

| DEPTH | Interval | PID | | | DESCRIPTION<br>NAME (USCS Symbol): color, mottling, moisture, percent distribution of coarse and fine grained material, angularity, plasticity and dilatency (if predominately fine grained), relative density/conitency, cementation, structure, minerals and alteration, odor, geologic interpretation (eg. Native Soil) | ADDITIONAL INFORMATION |
|---|---|---|---|---|---|---|
| 0–15 | No Sample | | | | | |
| 5 | | | | | | |
| 10 | | | | | | |
| 15 | | | | | Poorly graded sand (SP): very dark gray (2.5Y 3/1); 95% fine sand, 5% silt, moist | |
| | | 0.0 | | | ↓ grades to black (2.5Y 2.5/1) & increasing grain size to fine to medium sand; trace silt, moist | |
| 20 | | | | | Poorly graded sand (SP): very dark grayish brown (2.5Y 3/2) moist 95% f. m. SAND, 5% low plasticity silt; w/ laminated low plastic silty sand lenses from 21-21.5' (75% f. sand, 25% silt, | , 85% silt w/ sand lenses, 100% silt 100% fine sand |
| | | 0.0 | | | Poorly graded sand (SP): black (2.5Y 2.5/1) 100% fine & medium sand, trace silt, wet | sample crushed in core preventing good recovery |
| 25 | | 0.0 | | | | |
| | | | | | Boring terminated @ 27.5' bgs | |
| 30 | | | | | DRF-2/4/1 | |

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|---|---|---|---|

| | | | |
|---|---|---|---|
| PROJECT: FRP $CO_2$ Injection | | LOG OF BORING: IMW B1-D | |
| BORING LOCATION: | | ELEVATION AND DATUM: | |
| DRILLING CONTRACTOR: Cascade | | DATE STARTED: 2/8/18 | DATE COMPLETED: 2/8/18 |
| DRILLING METHOD: Direct Push Same as 2/7/18 details | | TOTAL DEPTH: 50' | MEASURING POINT: Ground surface |
| DRILLING EQUIPMENT: Geoprobe 7822DT | | DEPTH TO FIRST WATER: not w/in sampling interval | DEPTH TO FREE WATER |
| SAMPLING METHOD: macrocore w/liner | | CASING: | SCREEN INTERVAL: |
| BOREHOLE DIAMETER: 2 1/4 pilot w/ 3 3/4 over drill casing | | LOGGED BY: K. Black | |
| HAMMER TYPE/SYSTEM: NA | | | |

| DEPTH | Recovery Interval | PID | | | DESCRIPTION<br>NAME (USCS Symbol): color, mottling, moisture, percent distribution of coarse and fine grained material, angularity, plasticity and dilatency (if predominately fine grained), relative density/conitency, cementation, structure, minerals and alteration, odor, geologic interpretation (eg. Native Soil) | ADDITIONAL INFORMATION |
|---|---|---|---|---|---|---|
| 10 | No Samples | | | | | |
| 20 | | | | | | |
| 30 | | | | | | |
| | | | | | poorly graded sand (SP): Black (5Y 2.5/1), wet, 100% fine to medium sand, trace silt | |
| | | 0.0 | | | | |
| 40 | | | | | | |
| | | 0.0 | | | | |
| | | | | | ↓ slight increase in silt content: [illegible]% f. M. sand, 5% silt | |
| | | 0.0 | | | | |
| | | | | | silty sand (SM): dark gray (2.5 Y 4/1), wet, 75% fine sand w/ 25% medium plastic silt, lenses of medium plastic silt | |
| 50 | | | | | Boring terminated @ 50' set well. see reverse for well construction details | |
| | | | | | Ecology BKF-250 | |

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